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GENERAL SCIENCE

PART I

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PREFACE

THIS volume is the first of a series designed to include the basic principles of physics, chemistry, and biology. The authors aim at broadening the pupil's outlook by dealing with the elementary principles of these subjects, not only from the purely scientific standpoint, but also in their application to everyday things. In this way they hope that the study of science will exert a humanising influence on the pupil. At the same time they claim that in such a course one can train the pupil in scientific habits of thought.

The present volume consists of an introductory course of physics and chemistry which should normally be taken at ages eleven to twelve. The authors have included some practical measurements, which they believe to be essential to the laying of sure foundations of scientific knowledge. Where there is a mathematical laboratory, or where the same master teaches mathematics and science in the first year, it may be possible for this work to be done in the mathematical lesson. Certainly there must be close co-operation between the teachers of mathematics and science at this stage, so that the facts of mensuration discovered in the laboratory may be used in working examples.

After performing the experiments, students are expected to write a clear connected account, with sketches where necessary, answering the questions as they arise. Disconnected notes must be discouraged. The experiments in this volume have been so arranged that all weighings, with the exception of a few in demonstration experiments, may be done by spring-balances of various sizes. This will save valuable time which may more profitably be spent on the other parts of the syllabus.

In this first-year course the authors have included very few numerical examples. These are collected at the end of the book. This has been done after careful consideration, because the work at this stage being largely experimental and the pupils young, easy oral examples should in the main suffice to emphasise the facts and principles learnt.

The authors are indebted to many sources for certain of the illustrations, for which due acknowledgment is made in the text. They would also like to thank Mr R. Jeffery, M.A., of the Cedars School, Leighton Buzzard, and Mr B. M. Neville, B.Sc., of William Ellis School, London, for kindly reading the MS. and proofs, and for making many valuable suggestions.

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GENERAL SCIENCE

PART I

CHAPTER I

INTRODUCTION

Let us try to imagine the world as it was about a hundred years ago. The streets of towns were very badly lit by candles and oil-lamps, the use of gas being quite a new feature. Electric light was unknown. There were no gas stoves or gas cookers, and all cooking had to be done by coal or wood stoves. The era of the train and omnibus had not yet begun. A journey from London to Bath, which now takes about two hours by rail, and may be done in half an hour by a fast aeroplane, then took twelve hours by stage-coach. Readers of *Tom Brown's Schooldays* will remember the description of the hardships of Tom Brown's stage-coach journey from Islington to Rugby. At that time aeroplanes were only dreamt of, and such wonders as wireless and television were not even thought of. There were no great ocean liners driven by steam or oil, only sailing ships which took months to cross the Atlantic. Food brought from abroad often went bad on the way, for there were no ice chambers to keep the meat and fruits fresh as there are to-day. There are still a few people alive whose fathers fought at the battle of Waterloo, and these people have witnessed the gradual speeding-up of life by railway trains, motor-cars, aeroplanes, and airships; they have witnessed the beginnings of wireless and of telephony, the marvels of X-rays, by which the interior of the body may be viewed and photographed. They have seen the enormous progress made by medical men in the combating of diseases. Truly these achievements are as wonderful as any ancient fairy tale. What the next century will bring forth no one can tell. One thing, however, is certain, that science will continue to confer benefits on humanity by mastering nature's secrets. Ages ago man feared nature and thought that evil spirits dwelt in every stone and tree. He offered up sacrifices, often human sacrifices, to these imagined spirits. These times, happily, are now past, at any rate in civilised countries, and this is partly due to the march of science, which has enabled man to overcome his fear of the forces of nature and to bend them to his will. It should ever be remembered that Nature reveals her secrets to the patient thinker alone. Although man has still far to go in the realm of discovery, he has already gone far in the harnessing of the forces of nature and of putting them to his own use.

This book is put into your hands in the hope that you may learn something of the methods of the great discoverers, and feel, even in a small degree, the thrill of discovering things for yourself.

THE BUNSEN BURNER, THE GAS FIRE, PRIMUS STOVES

In your practical work in Science you will constantly be called upon to use a piece of apparatus called a Bunsen burner (see fig. 1 (*a*)). This burner was invented by a German scientist named Bunsen about 1855. The principles underlying this burner are applied in the construction of gas fires and gas cookers, and the following experiments will enable you to understand how it acts.

1. Unscrew the chimney, turn on the gas and light it at the jet. *Describe the appearance of the flame.*

2. Turn out the gas, replace the chimney, close the holes by turning the collar, turn on and light the gas. *Is the flame anything like it was before?* If it gives light the flame is said to be *luminous.*

3. Gradually open the holes. State what happens to the flame as you do this. *Is the flame still luminous?*

4. Which is the steadier, the luminous or the non-luminous flame?

5. If the holes are large enough the flame may "roar." Try to make it silent and yet non-luminous. *How is this done?*

6. Again close the holes and hold a piece of porcelain over the flame for a few seconds. *What happens to the porcelain?*

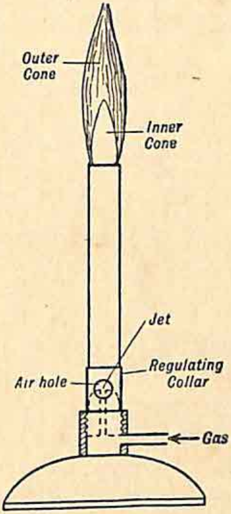

Fig. 1 (*a*)
The Bunsen burner

7. Clean the porcelain and repeat with the air-holes open. *Does the porcelain keep clean? Does this suggest to you a reason for the light of the luminous flame?*

8. Hold a match-stick or a chip of wood across the flame for a second or two just above the chimney. *What happens to it?* Illustrate by a sketch.

9. Quickly bring down on the non-luminous flame a sheet of thick paper (ordinary drawing paper will do). *As soon as it begins to char* remove it and blow on it to cool it. If it catches fire put it on the floor and stamp on it, then try again. Draw its appearance after it has been in positions X and Y (fig. 1 (*b*)).

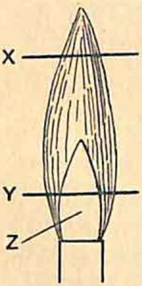

Fig. 1 (*b*).

10. Suddenly plunge a match head into the *inner* cone at Z

(fig. 1 (*b*)). Take it out quickly as soon as the wood begins to char. *What do you learn from this ?*

11. Try to melt a piece of thin copper wire by holding it across the flame in various positions. By this means ascertain roughly the hottest part of the Bunsen flame. Mark this in a sketch of the flame.

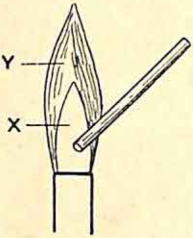

FIG. 2.

12. Hold a piece of glass tubing about 6 to 8 in. long so that the lower end is at X (fig. 2) and the tube is inclined at about 45° to the vertical. Apply a match to the top end. *What happens ?* Repeat with the lower end of the tube at Y.

From these experiments you should be able to find out something about the inner cone and the outer cone. Try to express this in words.

13. With the air-holes open wide turn off the gas slowly. *What happens to the inner cone ?* Repeat this experiment with the holes closed. *What difference do you observe ?*

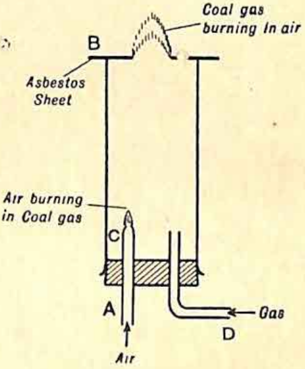

FIG. 3.

14. **Demonstration by Teacher**—The apparatus shown in fig. 3 consists of a glass chimney fitted at its lower end with a bung through which two tubes A and D pass. A is open to the air and D is connected to the gas supply. A sheet of asbestos, B, with a hole in it is placed over the top. First close the hole in B with the finger. Turn on the gas, and when you can smell it issuing from A apply a light there. Remove the finger from B and light the gas escaping there. The flame at A rises to C. As air is passing into the chimney through A it is evident that at C *air is burning in coal-gas* ; at B *coal-gas is burning in air*.

This experiment shows that although one may talk of "lighting the gas," it is equally possible to "light the air." It all depends on the surrounding atmosphere. The important fact is that a mixture of air and gas is necessary before "lighting" is possible.

15. **When does a Bunsen Burner light back ?**—Get a tin can with a lid which fits well, but which must not be pressed home too tightly (a 2-lb. Lyle's syrup tin will do). Make holes in the lid and the base each about half an inch in diameter. Tether the lid to the body of the can by a piece of string, as shown in fig. 4. Now close the top hole with your finger, and through a rubber tube pass in gas at the lower hole until the can is full. Turn off the gas supply. Place the can on a tripod and apply a light to the hole in the lid. The gas burns slowly. Watch the inner cone from a distance of a few feet. Describe what happens. As the gas burned at the top, air entered below. In time the gas and air in the can were mixed in the right proportions to explode, with the results you observed.

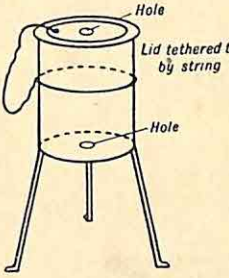

FIG. 4.

Try now with a Bunsen burner, lowering the flame and then gradually opening the air-holes. An explosion results, the flame travels down the tube and lights the gas at the jet. This is what happens when the burner "lights back."

If a Bunsen burner persists in lighting back how would you cure this fault ?

16. Heat an iron knitting-needle in a non-luminous flame until it is dull-red-hot. Try to light the gas of another Bunsen burner with it. Try again when the needle is bright-red-hot. The experiments should be tried several times. *Can the gas be lit with the needle only dull-red-hot ?*

The experiment shows that gas will not ignite unless the iron is at least red-hot. Nothing at a lower degree of heat (*i.e.* at a lower temperature) will do. The temperature at which the gas catches fire is called its *ignition point*.

The ignition of a gas or vapour by the common flint and steel lighter is a simple application of this principle.

17. Hold a piece of gauze an inch or so above a Bunsen

burner (fig. 5 (*a*)). Turn on the gas and light it above the gauze. Try to make the gas light below the gauze by lowering the latter until it is in contact with the burner. *Does the gas below the gauze reach its ignition point?*

Now light the burner and rapidly bring the gauze down on to it and hold it an inch above the burner (fig. 5 (*b*)). *What happens? Does the gas light above the burner at once?*

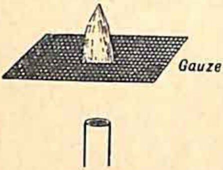

Fig. 5 (*a*).

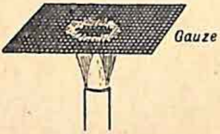

Fig. 5 (*b*).

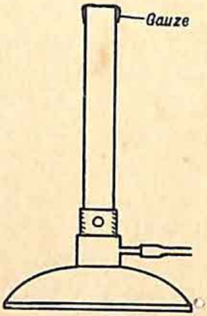

Fig. 6.

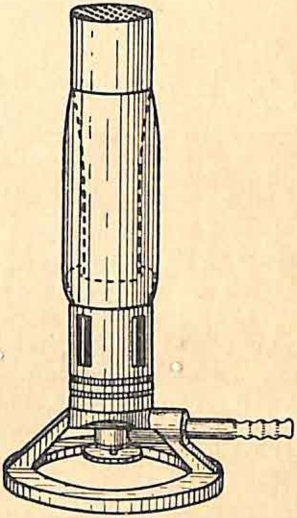

Fig. 7.—A Fisher burner (*Griffin & Tatlock*)

These experiments emphasise the fact that *gas will not burn below the temperature of red-hot iron.* They also show once again the ease with which a piece of gauze prevents the gas from reaching its ignition point.

18. Bend a piece of iron wire gauze of fine mesh so that it fits over the chimney of the Bunsen burner (fig. 6). Light the gas above the gauze. Open the holes as far as possible and turn the gas down gently. *Does the gas now light back?* The gauze robs the flame of its heat so rapidly that the gas below cannot reach its ignition point.

Special Bunsen burners are now made in which the mixture of gas and air passes through a nickel grid at the top of the chimney (fig. 7). The air-holes can be adjusted so that there is practically no inner cone and yet the gas does not light back. The flame is very hot indeed, and will even melt iron.

Sir Humphrey Davy applied the principles you have just considered in the miners' safety lamp.

The Miners' Safety Lamp—Davy was greatly concerned by the number of appalling explosions in the mines at the beginning of the last century, and he made experiments with a view to preventing them. The explosions were due to a gas called fire-damp, which is released during the process of coal-mining. When this gas is mixed with a certain proportion of air the mixture explodes if a light is applied. After years of patient experimenting Davy discovered that by surrounding a lamp with gauze the dangerous mixture would burn inside the gauze, but outside it the ignition point was not reached until the gauze became red-hot, which condition rarely occurs. Fig. 8 shows a form of safety lamp. It is noteworthy that Davy refused to patent his discovery, holding the view that an invention so beneficial to man should be available at as small a cost as possible. Through this invention countless lives have been saved. If you visit the Science Museum at South Kensington you may view the many lamps which Davy tried before adopting the final design. The Davy lamp is still in use in garages in cold weather for warming radiators of motor-cars. *It should never be opened so as to expose the flame near the car*, but when it is closed and burning it does not ignite any petrol vapour which may be near.

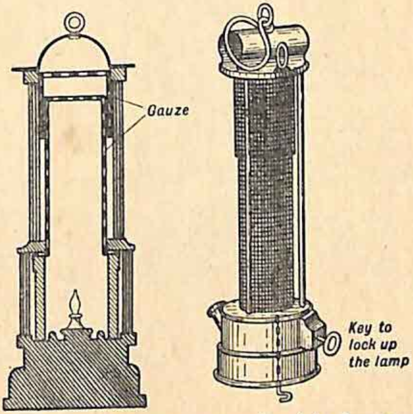

FIG. 8.—Davy's miners' safety lamp

You are now ready to put the knowledge you have gained to practical use at home. You should examine the gas cooker and gas fires, taking care not to damage either.

THE GAS COOKER

You will find that the principles underlying the use of the gas cooker are exactly the same as those of the Bunsen burner. The same precautions have to be taken to regulate the amounts of air and coal-gas.

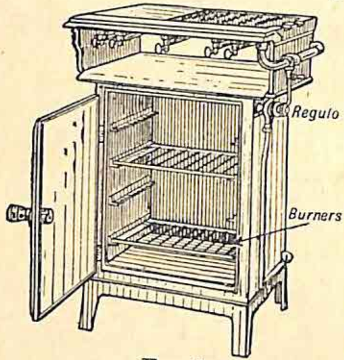

FIG. 9.

The most recent gas cookers are fitted with a device called the "Regulo," which controls the temperature of the oven and enables cooking to be carried out with the least possible attention. Note the position of the "Regulo" in fig. 9. A large diagram of the "Regulo" is given on p. 83, and also a description of how it works.

THE GAS FIRE

Fig. 10 shows the various parts of a gas fire. You should study the fire itself and identify the parts.

To light the fire, first turn the gas full on and *then* apply a light. Observe the flames: *How many parts do you notice in each?* When the fire has burnt for a minute or two turn off the gas and observe the radiants. They are now red-hot and send the heat out, which you can feel some distance in front of them. You should be able to adjust the air-holes so that you get the most heat from the burners and there is no danger of striking back. If your house is lit by incandescent gaslight you should find out how to regulate both gas and air so that the light is as brilliant as possible and there is no roaring.

The old-fashioned gas fires used to make a room stuffy. The modern gas fire, of which the "Radiation" type is a good example, ventilates the room as the gas burns. To understand how this acts do the following experiment with the Bunsen burner. Turn on the gas without lighting it and hold a piece of smouldering paper at the air-hole. Smoke emerges from the chimney, showing that the jet of gas draws in air through the air-hole. In the injector-ventilator of a modern gas fire there are two holes in the top. The current of burnt gas and air draws air from the room through one of these, and both escape into the chimney. Thus as the gas burns the room is ventilated.

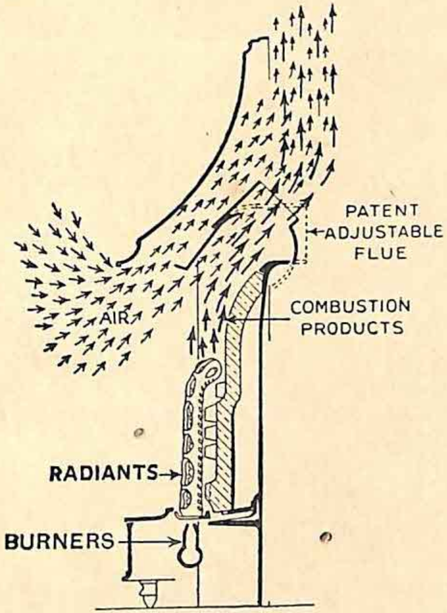

Fig. 10.—An injector-ventilator gas fire
(By courtesy of Messrs John Wright & Co.)

PETROL AND OIL STOVES

Some kinds of stoves, especially the "Primus" type, burn a mixture of oil vapour and air at some form of Bunsen burner. To start the stove the fuel must first be vaporised. The Primus stove is started by burning methylated spirits in the spirit cup (fig. 12). This heats the pipe leading to the jet. When the jet is hot, the oil which is under pressure (obtained by working a pump attached to the stove) is forced through the pipe and vaporises. It is then lit at the jet, and

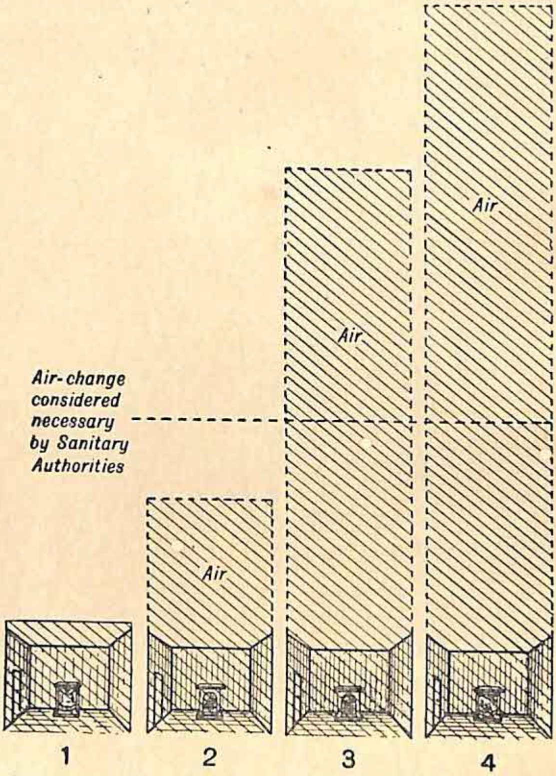

FIG. 11.—Views of a room (1) showing relative ventilation achieved by
(2) Ordinary gas fire.
(3) "Radiation" gas fire.
(4) Coal fire.
The room—(2) Would be stuffy.
(4) ,, ,, draughty.
(3) Gives nearly ideal conditions.
(By courtesy of Messrs John Wright & Co.)

a flame very like that of a Bunsen burner is obtained. The flame keeps the approaching oil vaporised. The action will be understood from fig. 12.

The lamp which the painter uses to burn off old paint is also a form of Bunsen burner, and is started like a Primus stove.

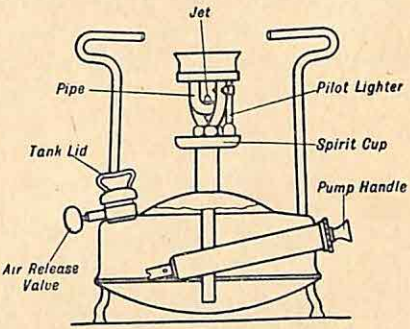

Fig. 12.—Section of a Primus stove

How to read a Gas Meter — Fig. 13 shows the arrangement of dials on an ordinary gas meter. The top dial has nothing to do with the record of gas consumed, but as it is marked in cubic feet, by observing it for a given time the number of cubic feet per hour which are being consumed can be determined.

When the pointer of dial D has gone round once, a thousand cubic feet of gas have been consumed. The pointer of C will then move one division. This principle applies also to the dials B and A.

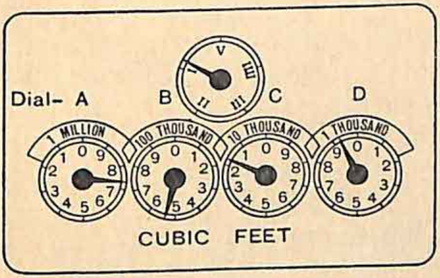

Fig. 13.—How to read your gas meter

To read the meter at sight start with dial A, putting down the lower figure (remembering that 0 may mean 0 or 10). Follow with the reading of dials B, C, and D. Add 00 after the figures so set down, and you have the present state of the index. Deduct the state of the index previously recorded, and you have the figures representing the consumption of gas since the last reading.

The above index reads 751,900. If the reading a week before had been 749,100, the amount of gas used during the week would have been 2800 cubic feet.

Incandescent Gas Burner (figs. 14 and 15)—This consists of a Bunsen burner which heats a "mantle" to white-heat, when it emits a brilliant light. (The mantle consists of 99 per cent. of thoria, which is the oxide of the metal thorium, and is obtained chiefly from a special sand found in Brazil and in the United States. The remaining 1 per cent. of the mantle is ceria, the oxide of the rare metal cerium. It is necessary to mix these two oxides in these proportions in order to get a really brilliant light.)

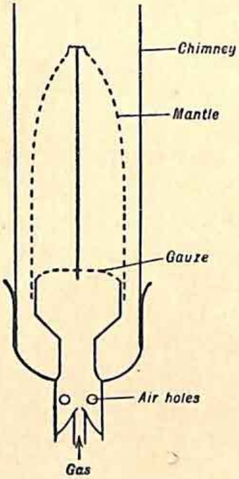

Fig. 14.

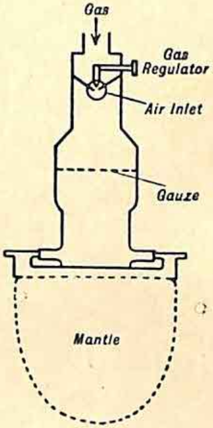

Fig. 15.

In both the upright and the inverted type the mixture of gas and air passes through a gauze. *Why is this?* You should examine both types of burners and find out how to adjust the gas and air mixture. The advantage of the inverted type is that the shadow of the burner is projected upwards; the disadvantage is that the burning gases in time cause corrosion of the metal part.

CHAPTER II

SOME SIMPLE GLASS WORK
FILTRATION, DISTILLATION, AND EVAPORATION

ALL students of science should be able to make simple pieces of apparatus, and for this it is necessary to know how to bend and pull out glass tubing. A little practice in this art will soon lead to skill.

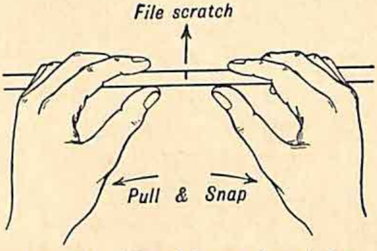

FIG. 16.—Breaking a glass tube

1. To pull out a Glass Tube—This will enable you to make a jet which can be used for a dropping tube or wash bottle.

(i) About 8 inches along a glass tube make a scratch with a small triangular file. Hold the tube as shown in fig. 16, and suddenly pull and snap it. It should break cleanly at the scratch (fig. 16).

(ii) Soften the ends by rotating in the edge of a Bunsen flame until the latter is coloured yellow. On allowing the glass to cool the ends will be found to be smooth.

(iii) Hold one end of the tube between the thumb and two fingers of the right hand, as shown in fig. 17. Allow the other end to rest lightly between the thumb and two fingers of the

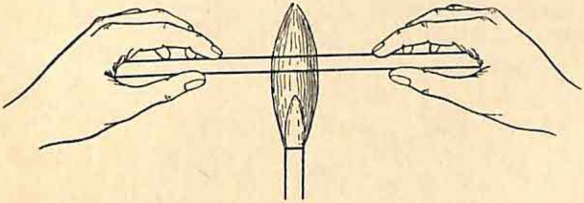

FIG. 17.—Softening a glass tube before pulling it out

left hand. Hold the tube with its centre just above the inner cone of the flame and rotate it steadily with the right hand, the left hand merely steadying it. The flame will become yellow and then the glass softens. *Take care not to twist the tube as it softens.* Then take the tube out of the flame, hold it vertically, and gently pull the ends apart. Stop pulling when the tube has shrunk in the centre to the required diameter. Allow it to cool, holding it straight meanwhile.

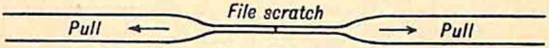

Fig. 18.

(iv) Make a file scratch in the middle of the narrow part and then *pull* the two ends apart (fig. 18).

2. **To break a very short piece from the end of a Glass Tube**—File almost completely round the tube, leaving a space, A, about one-tenth of an inch long (fig. 19). Heat the narrow end of a piece of tube which has been pulled out as in 1 (iv). Apply the hot point to A. *What happens? Can you suggest why?* The end may now be detached by a pull.

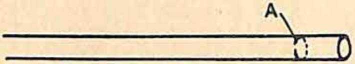

Fig. 19.—Breaking a narrow tube

3. **To cut a wide Tube, *i.e.* a Tube of half an inch or greater diameter**—Clamp the tube in the special holder shown in fig. 20. This may be made in the workshop, and should be fastened securely to the bench by a clamp. Wrap a piece of stout string completely round the tube and work it up and down until it begins to char. *Keep the string close to the edge of the holder all the time.* Rapidly pour a little cold water on the hot part of the tube, holding the protruding end in your hand. The tube should break cleanly. As the edges will be sharp it will be as well

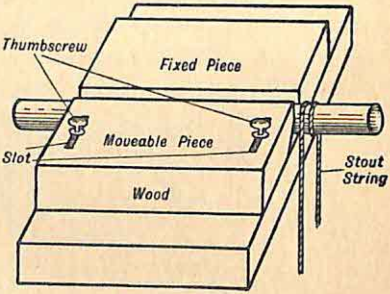

Fig. 20.

to grind them smooth. This is done by pouring a few drops of a 10 per cent. solution of camphor in turpentine[1] on to a piece of emery paper and grinding the glass on this by hand.

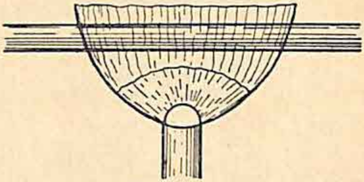
FIG. 21.—Heating a glass tube prior to bending

4. **To bend a Glass Tube**—Fishtail burners may be bought from the Gas Company. Fit one on the chimney of a Bunsen burner[2] and obtain a *luminous* flame. Rotate the tube in the position shown in fig. 21 until it is soft, remove from flame, and allow it to bend itself to the required angle.

5. **To fit up a Wash Bottle** (fig. 22)—You should have no difficulty in doing this if you follow the instructions given for drawing out and bending glass tubes. Start with a piece of glass tubing of suitable bore and about 18 in. long. Cut this into three pieces 6 in., 10 in., and 2 in. long respectively. Bend the 6-in. tube as shown at A and the 10-in. tube as shown at B. The nozzle C is made by rotating one end of the 2-in. piece in the edge of the Bunsen flame as in 1 (ii), but this time holding it there until the hole is very small. Round off the ends of the tubes and allow them to cool. Wet the tubes before inserting them into the stopper. Never use much force over this or the glass will break and cut your hand. The teacher should show you how to do it with safety.

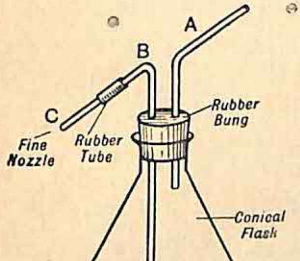

FIG. 22.—A wash bottle

Pour some water into the wash bottle and fit it up as shown in fig. 22. Blow down tube A. *What happens, and why?*

---

[1] 10 grm. of camphor dissolved in 90 grm. of turpentine.

[2] Use a bit of plasticine if necessary.

Blow down C. *What happens, and why?* Release the stopper and raise tube B so that it is above the surface of the water. Fasten the stopper in again and blow down A. *What happens, and why?* Release the stopper, and with B again below the water surface blow down A. *What happens, and why?* These experiments should teach you the essential features of a wash bottle. *What are they?*

The nozzle C is very small so that a very fine jet of water may be blown through, enabling a small quantity of water to wash thoroughly the residue on a filter-paper (see next exercise).

6. Some simple processes often used in Science Work: (i) Filtration—Stir up some sand and salt with water. Fit up a filtering apparatus as shown in fig. 23. Fold the filter-paper into four. Open it out as shown in fig. 24, leaving a closed space, and fit it into the funnel. Stir up the mixture of salt, sand, and water, and pour it into the filter down a glass rod, as shown in fig. 23. Notice the liquid which runs through the filter. *Is it pure water? How can you tell?* Use the wash bottle to wash the *residue* left on the filter-paper. A filter-paper can only remove matter *in suspension*, *i.e.* matter which is not soluble. It will not remove anything dissolved in the liquid. Water with salt dissolved in it is called a *solution* of salt in water.

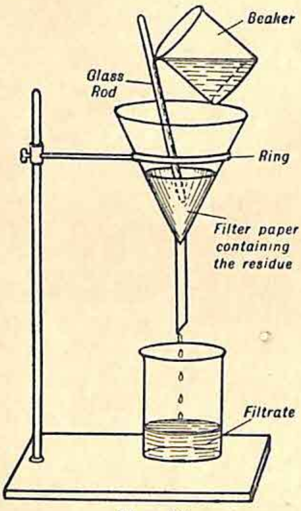

FIG. 23
The process of filtration

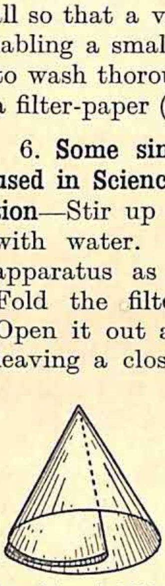

FIG. 24.—A folded filter-paper

(ii) **Evaporation**—Pour a little of the filtrate obtained in the last experiment into an *evaporating basin*. Arrange this on a piece of wire gauze on a tripod or a retort stand, as shown in fig. 25. Heat by means of a Bunsen flame, lowering the latter as the bulk of the filtrate diminishes. Do not allow the burner to light back. You know how to prevent this. Whilst this experiment is going on hold a clean cold surface, such as a piece of glass or porcelain, over the evaporating basin. *What happens, and why?* Taste the liquid deposited on the cold object. *Is it saline? What do you conclude?* When vapour or steam comes into contact with a cold object it is said to be *condensed. What remains in the basin?*

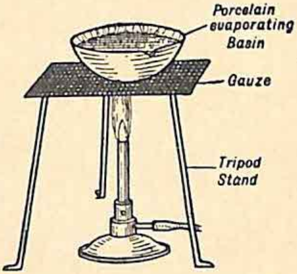

FIG. 25.—The process of evaporation

Did you notice a film of moisture on the under side of the evaporating basin immediately the lighted Bunsen was placed underneath? If you missed this, allow the flame to come into contact for a moment with a cold dry basin. Dry the basin, hold it over a stream of *unlit* gas. *Is moisture still deposited? Where did the moisture come from?*

(iii) **Distillation**—You have now obtained the solid impurities from the water with which you started. The insoluble sand was retained on the filter-paper. The soluble salt was obtained by evaporating the water, but you have lost the water. *Where has it gone? How did you catch a little of it?*

A German chemist named Liebig designed a piece of apparatus called a condenser, by which he could condense and collect a vapour given off during evaporation. This apparatus is shown in fig. 26.[1] The liquid which collects in the receiver is called the *distillate.* You should collect some of the distillate when your original solution is heated. Taste it, and also completely evaporate a little. If there is no residue you may conclude that the distillate was pure water.

You should write a full account of this experiment in your notebook under the heading "To obtain pure water from a solution of salt in water." Draw a good sketch and name the various parts.

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[1] *Note for Teachers*—The authors have found it satisfactory to have five sets of this apparatus for a class of thirty, each group of six pupils being responsible for fitting one up after a demonstration by the teacher.

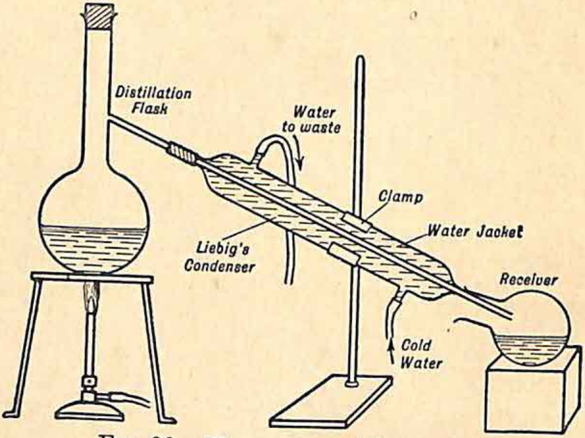


Fig. 26.—The process of distillation

(iv) **Crystallisation**—(*a*) Take a boiling tube and fill it about one-third full of water and heat in a water bath (fig. 27). Add nitre, a little at a time, shaking thoroughly after each addition, until after vigorous shaking a little remains undissolved. The solution is then said to be ***saturated***. Decant the clear solution into a clean evaporating basin. Be careful not to pour out any solid. Allow to cool slowly. When cold, pour off the liquid above the crystals into another evaporating dish. *Is this liquid pure water?*

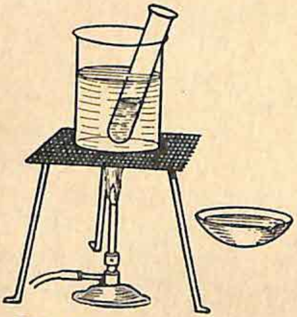


Fig. 27.—Crystallisation

(*b*) Dissolve a teaspoonful of alum in boiling water in an evaporating basin. Evaporate until crystals form in a drop removed on a glass rod. Allow the solution to cool slowly. *Did you find that a greater amount of substance can be dissolved in hot water than in cold? Can a saturated solution contain different amounts of substances dissolved in it? State on what the amount dissolved depends.*

Evaporation, Distillation, and Crystallisation in Nature—After every shower of rain the water on the ground gradually disappears. That which does not drain away evaporates into the air. The heat of the sun, helped by winds, is responsible for this. In the same way the sun's heat evaporates water from the sea. Eventually this water condenses and forms clouds, which consist of tiny particles of water. In time hundreds of these tiny particles may join together and form a big drop, which then falls as rain.

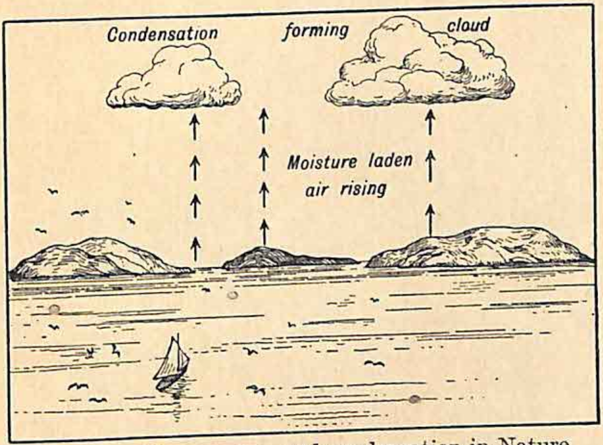


FIG. 28.—Evaporation and condensation in Nature

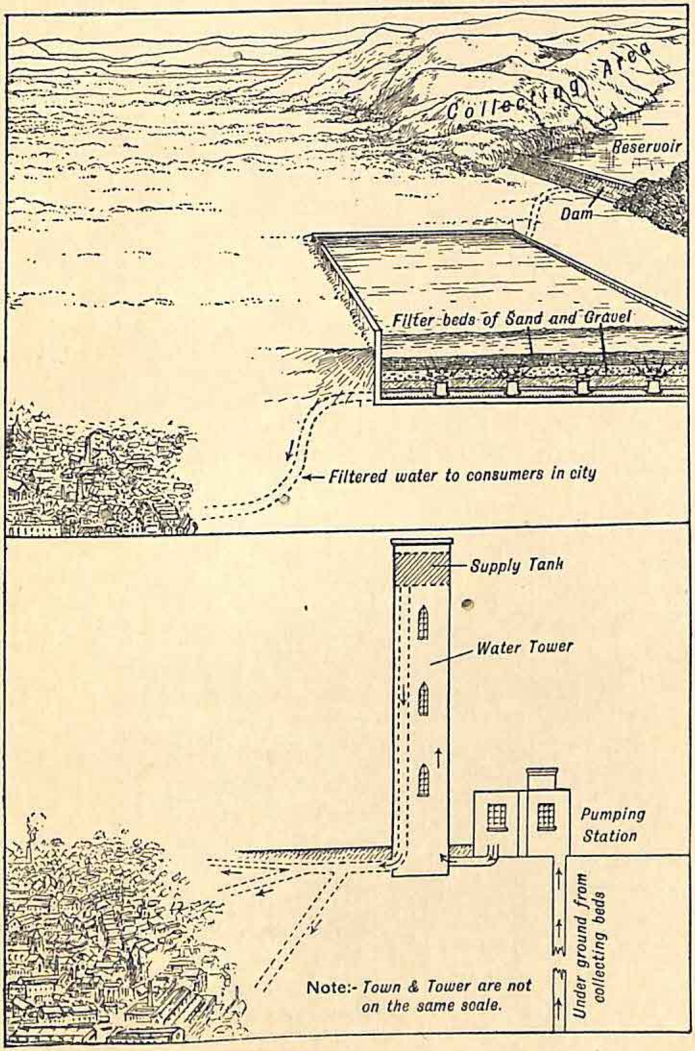
In some parts of the world there are great deposits of salt which have been left when a great sheet of water dried up. The salt is usually in the form of crystals, and these are often quite large, showing that the drying-up process has been slow. Examples are the salt deposits of the Caspian, the Dead Sea, and many dried-up lakes in the interior of Australia. It is interesting to learn that our word "salary" comes from the Latin *salarium*, meaning "salt money"—an allowance given to Roman soldiers in order to buy salt.

Why is the sea salty? You should now be able to answer this question. The rain washes soluble substances out of the soil and rocks. These in time make their way into the sea. As the sea-water evaporates the dissolved solid matter is left behind. As dissolved solid matter is constantly finding its way into the sea, the latter gets more and more salty. It is a fact that the Mediterranean is more salty than the Atlantic, and the Black Sea is still more so. The Dead Sea is a saturated solution, and as it is gradually drying up there are deposits of salt around its banks.

Although water is the commonest solvent, there are substances which will not dissolve in water, and for them special solvents are used. For instance, petrol and benzene dissolve oil or grease, and are used in "dry cleaning" to remove grease stains. The familiar rubber solution used in repairing punctures in rubber tyres is a solution of rubber in petrol.

Arabs scooping salt from the Dead Sea. The white mounds are heaps of salt crystals
(By courtesy of Palestine Potash Ltd.)

Filtration, Evaporation, Distillation, and Crystallisation applied by Man to his Needs—It is most important that the water supply of a city should be as pure as possible. It may come from a collecting area up in the hills and then the water from the filter-beds will simply run downhill in pipes to the houses and works which it supplies. On the other


Collecting Area
Reservoir
Dam
Filter-beds of Sand and Gravel
Filtered water to consumers in city
Supply Tank
Water Tower
Pumping Station
Under ground from collecting beds
Note:- Town & Tower are not on the same scale.

A town's water supply

hand, the water may have to be pumped from some depth below the ground on which the town stands. In this case it is usually pumped into a small reservoir or tower placed at a level higher than the town and led to the houses as described above. It will be interesting for you to find out how the drinking-water is supplied to your house.

On board ship pure water for drinking is obtained by distilling sea-water.

Crystallisation plays a very important part in the preparation of pure substances, *e.g.* Epsom salts, common salt, nitre, and alum. The principles underlying the commercial process are the same as those you have employed, except that tons of material instead of ounces are obtained.

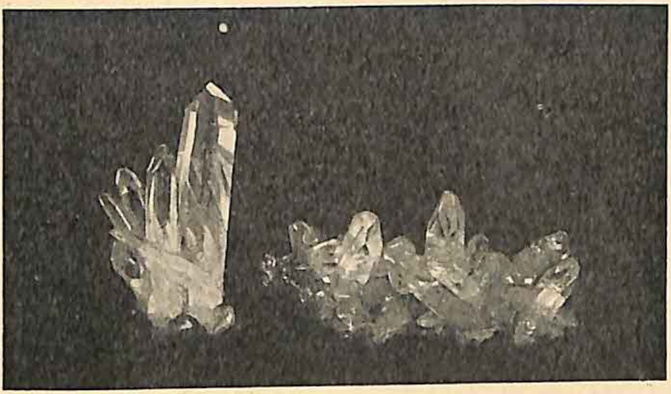
Experiments with Crystals—(i) Heat some washing-soda crystals in an evaporating dish. Hold above it a test-tube containing cold water. The outside of the tube must be dry at the start. *Does it remain dry?* If not, *where does the moisture come from?* It is called *water of crystallisation.* When no more water is expelled, allow to cool. The soda is now *amorphous*, *i.e.* of no definite shape. Add a drop of water. *What happens?* Add another drop or two.

(ii) Repeat the above experiments with copper sulphate crystals. This may be bought under the name of blue vitriol. Make a note of all the changes which occur. Heat carefully until all the water of crystallisation is expelled. When cool divide into three portions; to one portion add a drop of water, to the second add a drop of absolute alcohol [1] which is free from water, and to the third add a drop of methylated spirits which contains a little water. You ought now to have discovered a test for the *presence* but not for the *purity* of water. *What is it?*

(iii) Dissolve a small crystal of cobalt chloride in one-third of a test-tubeful of water. Using a splint of wood, write a few words with the solution on white paper and allow to dry. Hold the paper some distance above a Bunsen flame and note that the "invisible ink" becomes visible. This can be used by scouts to send dispatches that might fall into the enemy's hands.

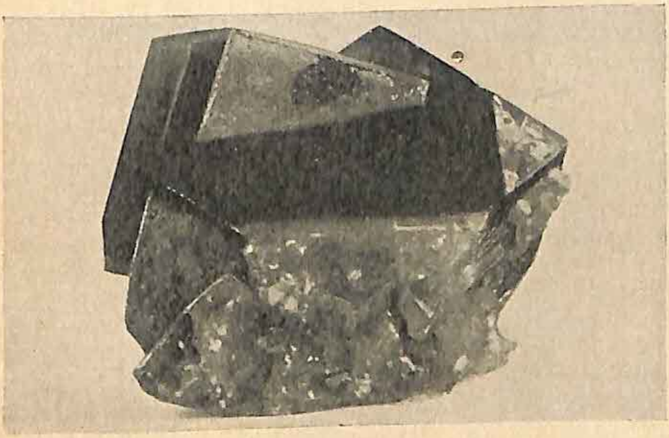
[1] An ounce or two of this will last a long time.

NATURAL CRYSTALS



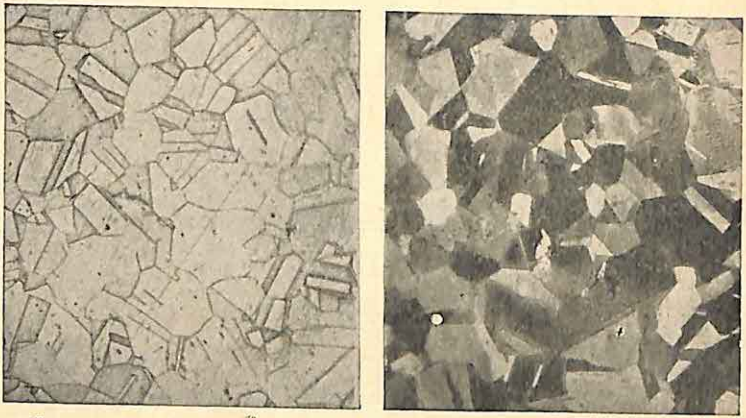
Quartz Calcite

(*By courtesy of the Geological Museum*)



Fluorspar *Photo: R. Jeffery*

The Formation of Crystals—It is very fascinating to watch the gradual formation of crystals under the microscope. Many schools have now projecting microscopes by which the growth of crystals may be shown to the whole class at once. A warm saturated solution of a substance such as nitre, Chili saltpetre, or sal-ammoniac is made. A drop is placed on a glass slide, and this is observed through a microscope or the image is projected on a screen.



1. 2. *Photo : D. Stockdale Cambridge*

Metal crystals. Magnification 70.
Coinage Bronze.

No. 1 is part of a penny which was annealed at red-heat, then ground, polished, and etched with a chemical solution.
No. 2 is the same after allowing it to oxidise in the air.

It is important to realise that not all crystals contain water of crystallisation. Examples are nitre and sodium chloride (common salt). Your teacher will no doubt be able to show you specimens of calcite and quartz. These minerals do not contain water. You should observe the beautiful crystalline shapes on a fresh piece of galvanised iron. These are crystals of the metal zinc, again without water.

Most metals are in the form of crystals, and the microscope is in extensive use to reveal their structure. By this means faults are discovered in metals used to make machinery.

CHAPTER III *

THE MEASUREMENT OF LENGTH

A Story of Long Ago—Ages ago our ancestors were savages, and lived in fear of every wild beast and of one another. Soon they began to live in communities for protection against their enemies. It is probable that these early communities lived in caves. At the entrance of a cave a fire would be kept burning to frighten away wild beasts. The first weapons were clubs and axes of stone; later, spears and bows and arrows were invented and helped man in his fight against nature. At first each family hunted and cooked its own food, and made its own simple clothes out of skins for protection against cold. As the communities grew larger it was found to be simpler for certain men to hunt whilst others prepared and mended the weapons. Some could grow the corn and others make the clothes. In this way, slowly but surely, arts and crafts developed. Imagine a scene in this early civilisation. Big Bill the Hunter has broken the thong of his bow, and has come to Little John the Thong-maker to buy a fresh supply of thongs. With him he brings a deer which he has slain. Says Big Bill, "What length of thongs will you give me for this deer?" "Let me look at it," says Little John. After inspection the latter says, "I will give you five lengths for it." After some argument Little John decides to give six lengths, and he proceeds to measure each length from chest to the finger-tips of his outstretched arm. "That won't do," says Big Bill, "you must let me measure the thongs." "Oh no," says Little John. "But I insist," says Big Bill, getting out his club, and Little John has to agree or be knocked down by the bully. In this way the stronger man could be sure of getting the better of a bargain, as his arms were longer than those of his opponent. But time arrived when the small men banded together in order to get justice, and petitioned the Head Man of the tribe to judge matters of this sort. At first the Head Man ordered the disputants to fight it out, but eventually a Head Man wiser than his predecessors saw that this only caused the death or injury of men who were needed to fight the enemies of their tribe. This wise man made a decree that the length of his arm should be the standard length, and ordered pieces of wood to be cut to this length and distributed through his territory for standard-length sticks. In some such way a standard of length first arose. Early methods of measurement were derived from something connected with man or his work. The *mile* was a thousand Roman paces, a pace being two steps. A team of eight oxen could pull a plough a "furrow-long" (*furlong*) before taking a rest. The pole used for prodding the oxen has given its name to the *rod*, *pole*, or *perch* (5½ yd.). Four of these rods make the surveyor's *chain* (22 yd.). In England the *yard* now in use is the distance from the tip of the nose of King Henry I to the end of his thumb when he stretched out his arm, and was at first called an *ell*. The *inch* was declared in 1224 to be the length of three dried grains of barley-corn placed end to end. In the Exchequer Offices in London there is a bar of platinum in which two plugs of gold are sunk. The distance between these at a temperature of 62° F. is the *standard yard*. If you visit Trafalgar Square you will find the common measures of length cut in the granite steps just north of the fountain. Every year surveyors have to test their tapes against this scale. Besides the yard, foot, and inch there is the chain, all these being marked out so that anyone can at any time check his measures. Anyone using a false measure has been liable to punishment from very early times. Do we not read in the book of Proverbs, "A false balance is an abomination unto the Lord"?

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* Chapters III, IV, and V may be done in the mathematics lessons. (See Preface.)

Measures of all kinds vary in different countries, and travellers often find difficulty on account of this fact. Scientific men in all countries have agreed to use the same measures, not only of length, but of area, volume, weight, etc., as well, for scientific work.

Scientific Measures of Length—In 1790, during the French Revolution, the National Assembly appointed a committee of scientific men to settle all standards of weights and measures. They were instructed to make accurate standards, which could not only be kept for comparison, but which could be reconstructed if by any chance the originals were lost. This committee decided to take as the standard of length one ten-millionth of a quarter of the earth's circumference, measured from pole to pole. This was called a metre. Two scratches, a metre apart, were made on a bar of platinum, which was kept at Paris for comparison. Later it was found that the measurements of the committee were not quite accurate, but it was decided to keep the same platinum bar as the standard metre. This standard metre and other standards copied from it are now kept at the International

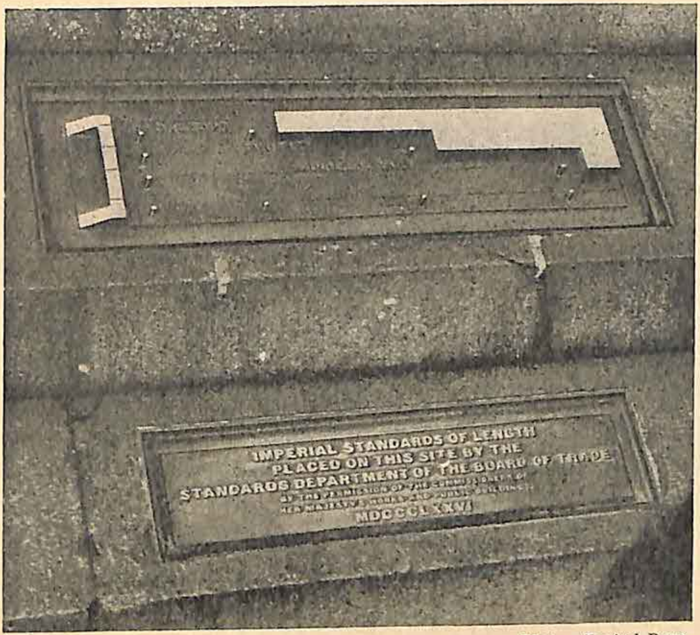

IMPERIAL STANDARDS OF LENGTH
PLACED ON THIS SITE BY THE
STANDARDS DEPARTMENT OF THE BOARD OF TRADE
MDCCCLXXVI

Photo: Topical Press

Some of the standards of length in Trafalgar Square

Bureau of Weights and Measures, Sèvres, near Paris. There is also a copy at the office of weights and measures in every civilised country.

You should now examine the metre stick and compare it with the English yard. The metre is divided into 10 *decimetres*, each of these is again divided into 10 *centimetres*, which are each subdivided into 10 *millimetres*. Most of your measurements will be expressed in *centimetres*, a millimetre being 0·10 of a centimetre. Multiples of the metre are respectively Deka-, Hecto-, and Kilo-metres. The one commonly used for great distances is the *Kilometre*, which is approximately $\frac{5}{8}$th of a mile. The following table sets out the various units of length in the metric system and their relation to each other and to the metre :—

10 millimetres (mm.)	=1 centimetre (cm.).	1 mm. =	0·001 M.
10 centimetres	=1 decimetre (dm.).	1 cm. =	0·010 M.
10 decimetres	=1 *Metre* (*M*.).	1 dm. =	0·100 M.
10 metres	=1 Dekametre (Dm.).	1 Dm. =	10·0 M.
10 Dekametres	=1 Hectometre (Hm.).	1 Hm. =	100·0 M.
10 Hectometres	=1 Kilometre (Km.).	1 Km. =	1000·0 M.

In the following exercises you will use the inch and the centimetre, each divided into tenths. A length of 4 inches 3 tenths will be written 4·3 inches. A measurement of 7 cm. 6 mm. will be written 7·6 cm.

Exercise 1—To discover the Precautions to be taken in making an accurate Measurement by means of a Ruler

Place the ruler across two parallel lines AB, CD, as shown in position XY (fig. 29), arranging it so that the mark 1 on the ruler is on AB with one eye placed above the line AB, the other being closed. Hold the ruler quite firmly in this position and move the eye until it is above the line CD. Note the distance between AB and CD.

Still holding the ruler in its first position, move the head so that your eye is about 1 foot to the left of the line CD. Note the point on the ruler where the line appears to cut it.

Repeat with head 1 foot to right of CD.

Repeat the three readings with the ruler held in position XY′.

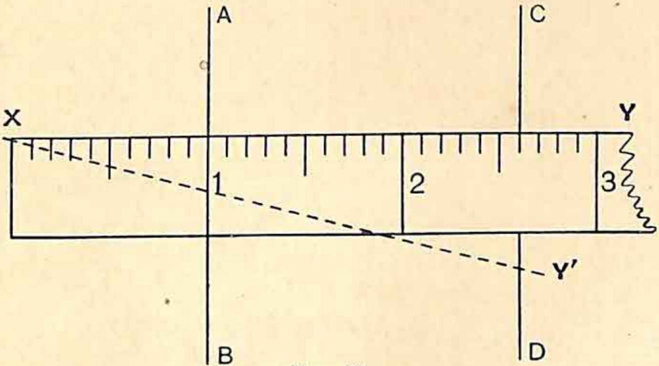


Fig. 29.

Results should be tabulated as follows :—

	Distance between AB and CD	Apparent distance when eye is 1 ft. to left of B	Apparent distance when eye is 1 ft. to right of B
1st position of ruler .			
2nd position of ruler .			

What conclusions do you draw as to the precautions to be taken in measuring a distance with a ruler ?

Exercise 2—To Measure Lengths as accurately as possible by Means of the Ruler

If all the precautions found necessary in the last exercise are observed, the lengths can be measured to two decimal places of the unit. The tenth marks on the ruler give the first place, and the second place is estimated. The tenth of an inch or centimetre, as the case may be, must be imagined to be divided into ten parts, and the second place of decimals is so obtained.

Let the line to be measured be AB. The distance XY represents an enlarged inch divided into tenths. It will be seen that AB is 3·5 in. and a fraction of a tenth. This fraction is quite plainly less than half a tenth and is approximately a third; it is about ·3 of one-tenth, *i.e.* ·03 of an in., and thus the line measures 3·53 in. The same method is adopted with centimetres, and after a little practice the second place of decimals will be fairly reliable.

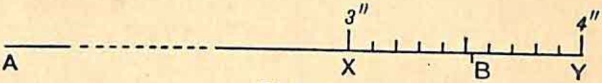


FIG. 29*a*.

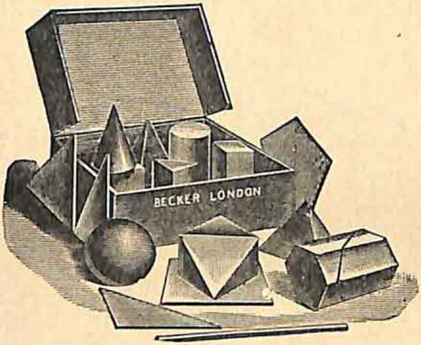


FIG. 30.—A set of geometrical models

Measure as many objects as you can in centimetres and inches, to two decimal places. In most schools sets of geometrical models are available for this purpose. Enter your results as shown below.

Methods of measuring diameters of cylinder and sphere are shown in figs. 31 and 32.

Results :

Object measured	Centimetres	Inches
Length of wooden block .		
Slant height of cone .		
Diameter of base of cone .		
,, cylinder .		
,, sphere . .		
Additions . . .	cm.	in.

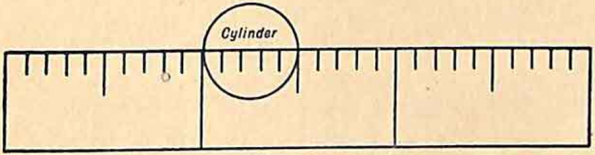


FIG. 31.

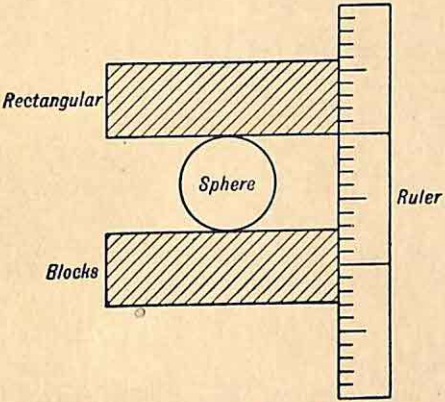


FIG. 32.—Measuring the diameter of a sphere

From your results you should be able to show that

1 in. = 2·54 cm.

Now plot a graph by means of which you can convert lengths up to 10 in. into centimetres, and *vice versa*. Your teacher will show you how to do this.

Exercises—(1) From your graph complete the following table :—

Inches	Centimetres
1·50	....
....	10·20
4·50	....
....	14·00
5·70	....
7·00	....

(2) The barometer reads 29·47 in. What is this in millimetres ? (Correct to first place of decimals.)

(3) Express 1 mile in Kilometres (1 in. = 2·54 cm.).

(4) Express 1 Kilometre in miles.

(5) Draw a graph by which you can convert 0 to 100 Kilometres into miles. This would be useful to an Englishman motoring in France.

Exercise 3—Measurement of the Length of a Curved Line

1. *By Means of a Thin Strip of Celluloid*—The method of procedure is shown in fig. 33—where the celluloid is used to measure the circumference of a circle. Make one mark, A, on the circle and another, B, near one end of the celluloid. Place these together and gradually bend the celluloid round the curve, a little at a time, as shown. Make a mark C on the celluloid when A is again reached, and measure with a ruler the distance between B and C.

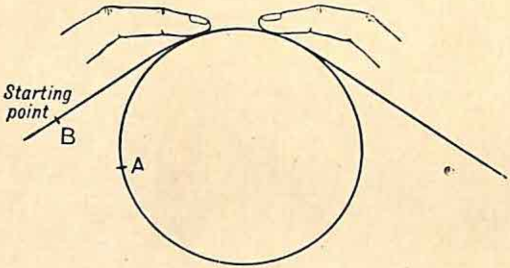


Fig. 33.

2. *Flexible Steel Tapes* may be obtained marked in centimetres and millimetres, and with one of these the length of a curved line is soon found.

3. *By Means of an Opisometer* (fig. 34)—Examine the instrument and note how the toothed or milled wheel moves along the axle. You can then decide whether you will have to push or pull the instrument along the curved line. It is important to start with the wheel close up to A. After

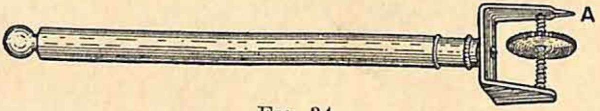
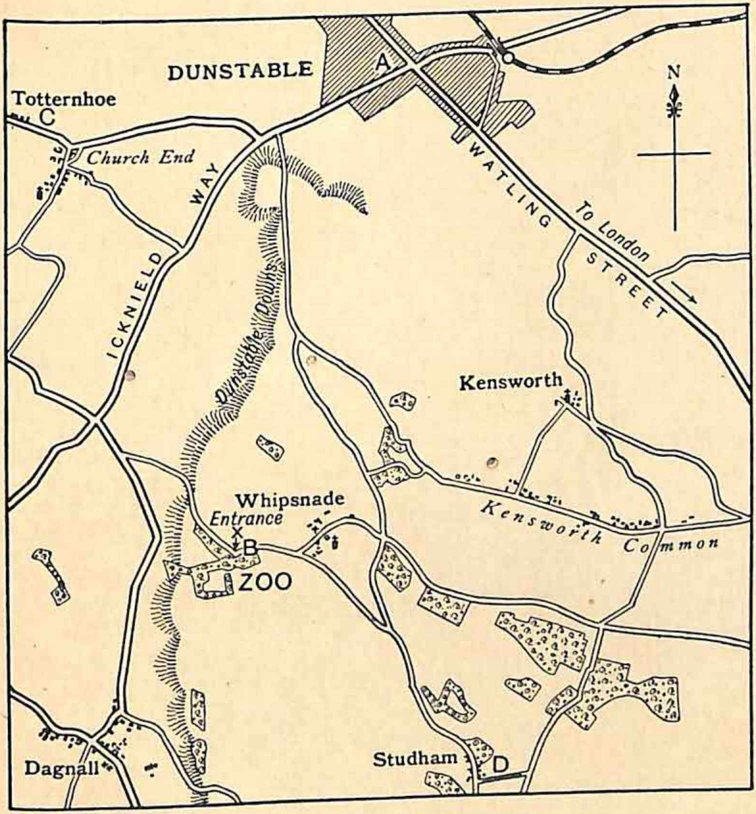


Fig. 34.

running the wheel along the curved line you can run it back along a straight line, and then measure the distance it has rolled. This instrument may be used to find the distance between two places on a map. (The distance has to be calculated from the scale of the map.)



Scale: 1 inch = 1 mile

FIG. 35.

Measuring Distances on Ordnance Maps—Distances between places may be found with fair accuracy by using an opisometer. For instance, suppose a map is to a scale of 2 miles to an inch and that the distance between places A and B, measured as above, is 2·38 in. This represents 2 × 2·38 = 4·76 miles.

Fig. 35 is a section of the one-inch Ordnance Survey Map, showing the position of Whipsnade Zoo. Find the shortest distance by road (i) from Dunstable (A) to the Zoo (B); (ii) from Totternhoe (C) to Studham (D).

Exercise 4—A Further Method of Measuring accurately to Second Place of Decimals. The Vernier

Make a scale of inches and tenths on the given cardboard (5 in. will be long enough) (fig. 36). Now divide a line ·9 in. long into ten equal parts (fig. 37).

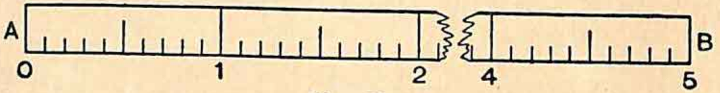


Fig. 36.

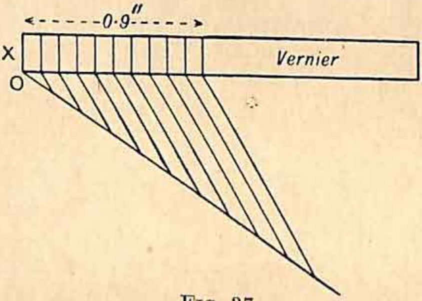


Fig. 37.

Cut out the rectangles AB and XY. AB is called the scale, XY the vernier.

Put the vernier beneath the scale so that 0 marks are in a line. What do you notice about the *difference* between the scale divisions and the vernier divisions?

What decimal of an inch does the difference equal in each case?

Now place the vernier so that the 0 mark is at what you think to be 1·25 inches on the scale. Which vernier division coincides with a scale division? Why does this coincide? Repeat, placing vernier mark 0 opposite 1·13 on scale, and find which vernier mark coincides with a scale mark.

Measure the lengths of the lines AB, CD, EF (fig. 38), using the vernier.

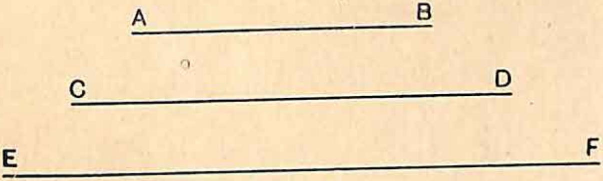


Fig. 38.

By Vernier

AB =
CD =
EF =

Exercise 5—Use of Sliding Vernier Calipers (a Vernier with jaws) (fig. 39)

Examine and make a careful drawing of the sliding calipers supplied. What is the unit of the main scale ? Into how many parts is the unit on the main scale subdivided ? What length of the main scale does the vernier cover ? How many vernier divisions are there in this length ? How many differences between the vernier and scale divisions make one complete scale division ? You should now be able to see that one of these differences is equal to 0·01 of a scale division.

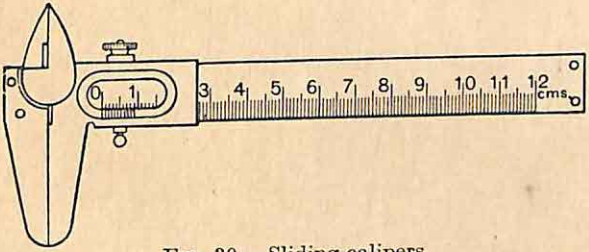


Fig. 39.—Sliding calipers

Use the instrument to find the lengths of the geometrical models supplied.

Tabulate results as shown below.

Object	Thickness in centimetres	Thickness in inches

Exercise 6—The Relationship of the Circumference of a Circle to its Diameter—(1) *Measure the circumference of a circle, diameter* 1·5 *to* 3 *in., in as many ways as you can.* Measure the diameter, and from your results find how many times the diameter divides into the circumference.

Results :

	Circumference	Diameter	$\frac{\text{Circumference}}{\text{Diameter}}$
(*a*) By celluloid .	cm.	cm.	
(*b*) By steel tape .	Mean result ....cm.		
(*c*) By opisometer .			

(2) *Find the circumference of several metal cylinders as follows:* Wrap several turns (about 10) of cotton thread closely round (fig. 40). Draw a pencil or ink line through the cotton, parallel to the axis of the cylinder. Unwrap the cotton and measure 10 turns. Hence find the circumference.

Find the diameter, using sliding calipers.

Repeat exercise, using a pencil. *Remembering that the thread has a thickness, which do you think will give the least error in the above experiment, the thick cylinder or the pencil?* Suggest a reason.

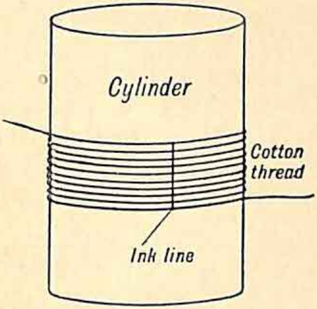


FIG. 40.

Results :

Length of 10 turns = cm.
$\therefore$ circumference = cm.
Diameter by calipers = cm.

$\therefore$ circumference $\div$ diameter $= \dfrac{\ldots\ldots}{\ldots\ldots} = \ldots\ldots$

The result $\dfrac{\text{circumference}}{\text{diameter}}$ is called π,[1] and is 3·14. This is approximately $\dfrac{22}{7}$.

Problems—(1) The diameter of a bicycle wheel is 28 in. How many times will the wheel revolve in going 2 miles ?

(2) The circumference of an iron pipe is 14·13 in. Find the outside diameter. If the iron is 0·25 in. thick, what is the internal diameter ?

(3) A donkey is tethered to a peg by a rope 15 yd. long. What is the circumference of the greatest circle the donkey can trace round the peg ?

(4) How would you find the diameter of the circular end of a large cylindrical boiler ?

Exercise 7—Measurement of very Small Lengths such as the Thickness of a Wire—This is done by means of a *screw gauge.*

Examine the screw gauge provided. First close the jaws gently and note if the bevelled-edge scale reads 0. If it does not, an allowance must be made in the measurements. Unscrew the gauge carefully, giving the bevel 10 complete turns. You will find that as the jaws recede the scale, usually in millimetres, appears under the bevel. If the edge of the bevel moves 10 mm. in 10 turns, the *pitch of the screw* is 1 mm. (In some gauges the pitch is only 0·5 mm.)

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[1] Pronounced *pi.*

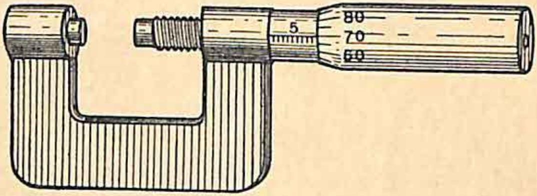

Fig. 41.—A screw gauge

How many divisions are there on the bevel scale? How far do the jaws separate when the bevel turns 1 division?

Exercise—*Use the screw gauge to find the diameter of several different wires.* Precaution: never exert pressure, but close the jaws on to the wire very gently so that any soft wire, such as copper, is not crushed, thereby reducing the diameter. Compare your results with the diameters given in a *table of standard wire gauges* (S.W.G.).

Results:

Wire	Measured diameter	S.W.G. diameter
Copper, No. 22	mm. (*a*) (*b*) } mean mm.	mm.
Iron, No. 16 .		
Eureka, No. 28		
Etc. . .		

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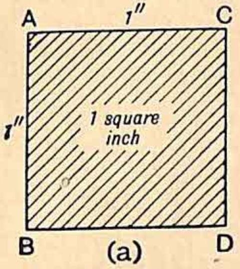
CHAPTER IV

THE MEASUREMENT OF AREA

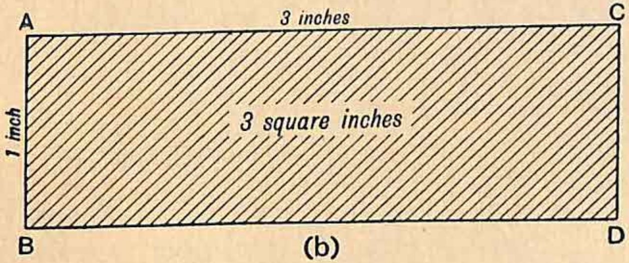
1. Rectangle—AB is a straight line 1 in. long. Imagine it to be moved for a distance of 1 in. in a direction perpendicular to its length. It will now occupy the position CD, and it will have traced out the shaded area in fig. 42 (*a*).



(a)

Fig. 42.

The figure ACDB is called a rectangle because all its angles are right angles. It is also a square, as its sides are equal as well. Its area is called 1 sq. in. If AB is moved 3 in. in the same direction, it traces out a rectangle of three times as much area as before—namely, 3 sq. in. (fig. 42 (*b*)).



(b)

Fig. 42.

If AB is 2 in. long and is moved 3 in. in a direction perpendicular to its length, it traces out the rectangle shown in fig. 42 (*c*). *What is the area of this rectangle?*

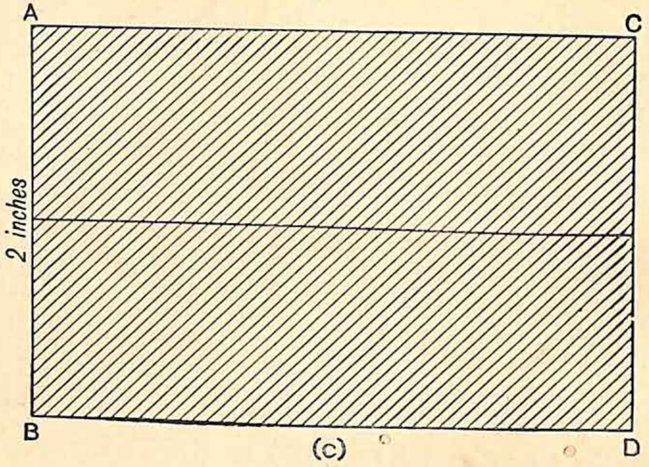


Fig. 42.

What is the area of the following rectangles :—

(*a*) Traced by a straight line 3 in. long moving 4 in. perpendicular to its length ?

(*b*) Traced by a straight line 4 in. long moving 5 in. perpendicular to its length ?

(*c*) Traced by a straight line 0·5 in. long moving 6 in. perpendicular to its length ?

(*d*) Traced by a straight line 2·5 in. long moving 4 in. perpendicular to its length ?

What is the simplest way of finding the area of any rectangle ?

Fill in the following tables :—

English System	
Length	*Area*
.... in. = 1 ft.	.... sq. in. = 1 sq. ft.
.... ft. = 1 yd.	.... sq. ft. = 1 sq. yd.
	4840 sq. yd. = 1 acre
	640 acres = 1 sq. mile

Metric System

.... mm. = 1 cm.
.... cm. = 1 dm.
.... dm. = 1 M.
.... M. = 1 Dm.
.... Dm. = 1 Hm.
.... Hm. = 1 Km.

.... sq. mm. = 1 sq. cm.
.... sq. cm. = 1 sq. dm.
.... sq. dm. = 1 sq. M.
.... sq. M. = 1 sq. Dm.
.... sq. Dm. = 1 sq. Hm.
.... sq. Hm. = 1 sq. Km.

Exercise—*Find the area in square centimetres and in square inches of two different-sized surfaces of the given rectangular block of wood.*

Tabulate results as follows :—

	Length	Breadth	Area	$\frac{\text{No. of sq. cm.}}{\text{No. of sq. in.}}$
Larger surface .	cm.	cm.	sq. cm.	(*a*)
	in.	in.	sq. in.	
Smaller ,, .	cm.	cm.	sq. cm.	(*b*)
	in.	in.	sq. in.	

What does the last column tell you ?

Can you suggest any other method of arriving at this number?

Draw a graph which will enable you to convert square centimetres into square inches and *vice versa*, and from the graph complete the following table :—

Square inches	Square centimetres
2·0	....
....	18·0
5·0	....
....	38·0

2. **Parallelogram**—If the straight line AB is moved parallel to itself in a direction AC, the area traced out is called a *parallelogram*, because the opposite sides are parallel. Fig. 43 shows the areas traced out by a line AB when moved in this way in different directions for the *same distance* AC. These areas are obviously *not* equal. *How would you move* AB *a distance* AC *so as to trace out the greatest possible area ?*

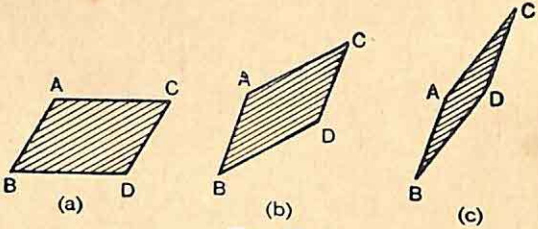


FIG. 43.

You should now perform the following experiment, which will enable you *to discover a simple way of finding the area of a parallelogram.*

On a piece of gummed tinted paper[1] draw two pairs of intersecting parallel straight lines about 2 to 3 in. apart. Letter the points of intersection as shown in fig. 44 (*a*). Draw AE perpendicular to AB. Cut out ABCD; cut also along AE and gum the two parts so as to make a rectangle in your book. This rectangle is equal in area to the parallelogram. *What is the area of this rectangle?*

AE is the *vertical height* corresponding to base DC.

Find the area of the parallelogram shown in fig. 44 (*b*).

(*a*) By multiplying CD by the corresponding perpendicular height.

(*b*) By multiplying BC by the corresponding perpendicular height.

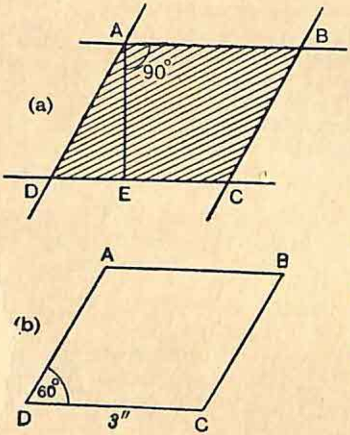


FIG. 44.

The area of a parallelogram is the *product of one side and the perpendicular distance between that side and the one parallel to it.*

3. **Triangle**—Again draw a parallelogram on a sheet of tinted paper. Draw the diagonal AC and cut along it (fig. 45).

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[1] Gummed tinted paper can be obtained from any stationer.

Can you make the two triangles coincide with each other? You have already found that the area of a parallelogram is

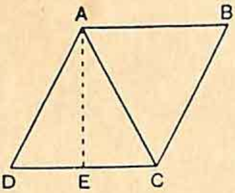


FIG. 45.

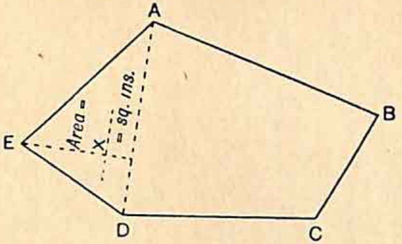


FIG. 46.

obtained by multiplying one side by the corresponding vertical height. *How would you obtain the area of a triangle?*

4. **An Irregular Rectilineal Figure. Method (*a*)**—Draw a large figure in shape something like that shown (fig. 46). Divide it into triangles, work out the area of each in square inches and square centimetres, and hence find the area of the whole. To check your result, divide the number of square inches into the number of square centimetres.

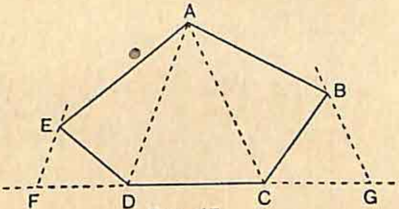


FIG. 47.

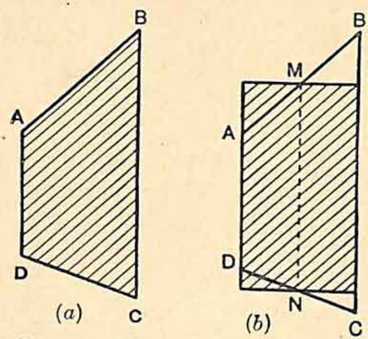
Method (*b*) (fig. 47)—By constructing a triangle equal in area to the figure and employing the method already used for finding area of triangle.

Join AD and AC. Through E and B draw EF and BG, parallel to AD and AC respectively, and meeting DC produced both ways. Join AF and AG. You should be able to prove the triangle AFG equal in area to the figure ABCDE. Therefore the problem reduces itself to finding the area of the triangle AFG.

Which of these methods (*a*) *or* (*b*) *is the simpler?*

5. **A Trapezium** (fig. 48)—ABCD is a quadrilateral which has only one pair of parallel sides and is called a *trapezium*. Draw

a similar figure on squared paper. Draw a line MN midway between the parallel sides. Through M and N draw lines at right angles to MN and obtain the shaded area shown in fig. 48 (*b*). Verify that the small shaded triangles at the corners are equal in area to those left blank. Thus *the trapezium* ABCD *is equal in area to the shaded rectangle.* MN is called the *mid-ordinate. Verify that it is equal to* **half** *the* **sum** *of the parallel sides of the trapezium* ABCD.



(*a*) (*b*)

FIG. 48.—Its area is that of the shaded triangle. MN is midway between AD and BC

The area of the trapezium is evidently *half the sum of the parallel sides × the distance between them*, or *the mid-ordinate × the distance between the parallel sides*. This is of special use in the following.

6. **The Mid-ordinate Method of finding the Area of any Irregular Figure**—Divide the figure by a number of equally spaced parallel lines, each, say, 1 in. apart. This process divides it into figures which are practically trapeziums. For instance, ABCD in fig. 49 is practically a trapezium, as AB and CD are very nearly straight lines. *What is the area of* ABCD?

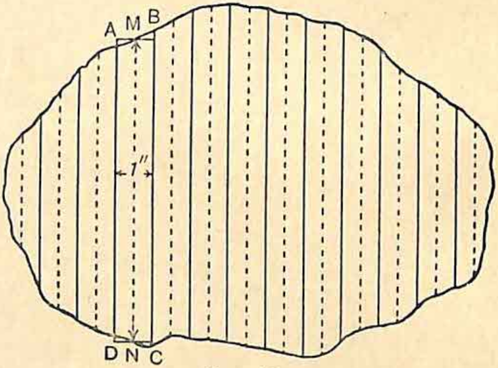


FIG. 49.

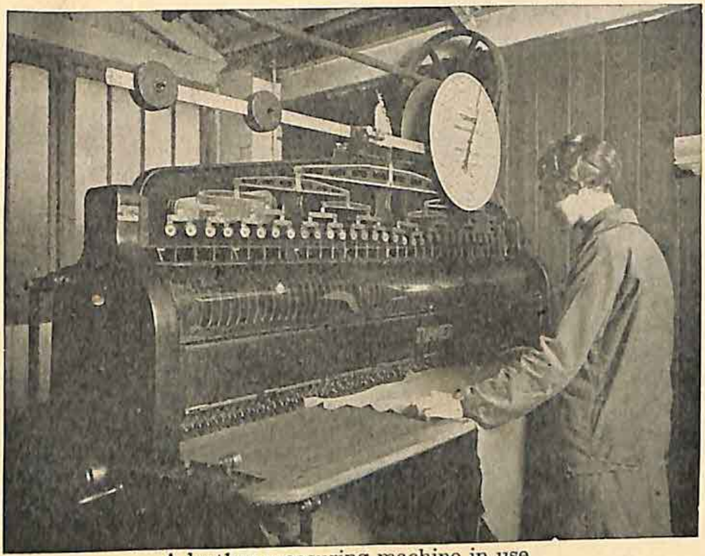
The area of any other strip is obtained by multiplying the mid-ordinate by the width of the strip.

Total area = width of one strip × the sum of the mid-ordinates.

The larger the number of equally spaced areas the greater the accuracy attained by this method.

The mid-ordinate method is of great practical use. By its means you can find the area of a map with a fair degree of accuracy.

A very interesting example of its use is in *measuring machines for finding the area of pieces of leather* in any large leather works. Such a machine is shown in the plate above. As the leather is passed through it a series of equally spaced wheels is rotated, each wheel measuring one of the mid-ordinates. Mechanism causes these measurements to be automatically added together and multiplied by the width of the space, the area being indicated directly on the large clock-like face. It is noteworthy that as the wheels only rotate when in contact with the leather, the area of any holes is not included in the measurement.



A leather measuring machine in use

(By courtesy of The Turner Tanning Machinery Co., Ltd., Leeds)

Suggested Exercise—Make a trace of a map of your county.

Find its area in square inches by the mid-ordinate method. Find the number of miles represented by 1 in., and hence the number of square miles represented by 1 sq. in. Hence calculate the area of your county in square miles.

7. **A Circle** (fig. 50)—On gummed paper draw a circle of any radius r. Divide it into sixteen equal sections. Cut these out and stick them alongside each other in your book.

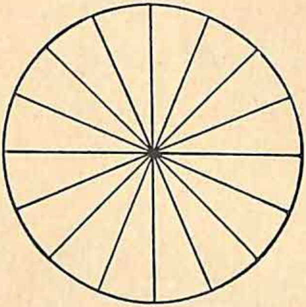


FIG. 50 (a).

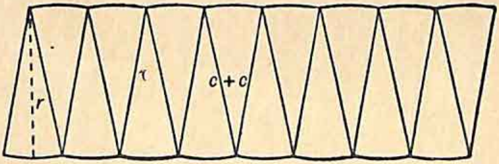


FIG. 50 (b).

You have a figure which is *almost* a parallelogram. The larger the number of sectors, the more nearly is the resulting figure a parallelogram.

What is the vertical height of this parallelogram?

Remember that the circumference of a circle is $2\pi r$. *What is the length of the base of the parallelogram? What is the area of the parallelogram?*

What is the area of a circle of radius r*?*

What is the area of a circle whose diameter is d*?*

Find the area of the circular faces of the objects supplied.

In each case measure the diameter as accurately as you can.

Results :

Object	Diameter	Radius	(Radius)^2	Area πr^2
1. Penny				
2. Cylinder, etc.				

Find the total surface area of each of the following solids: (*a*) rectangular block, (*b*) cylinder, (*c*) pyramid.

In each case state the number of surfaces possessed by the solid.

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CHAPTER V

THE MEASUREMENT OF VOLUME

You have already learnt that a moving point traces out a line, and that a moving line may trace out an area. Now consider what happens when an area is moved. Fasten cotton threads of equal length to the corresponding corners of two equal areas of the same shape, cut out in cardboard. These areas will completely coincide. If one area is pulled as far as possible away from the other, the threads, together with the cardboard ends, will show the outline of a solid. Such a solid is called a prism. Try this experiment with triangles, rectangles, circles, pentagons. Let ABCD in fig. 51 be a square inch and let it be moved perpendicular to itself. If it moves an inch it traces out a volume of 1 cu. in. If it moves 2 in. the volume traced out is 2 cu. in., and so on.

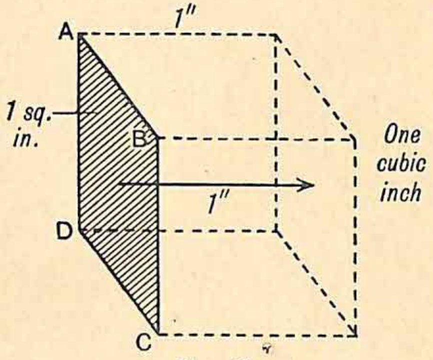


Fig. 51.

What is the volume traced out when the following areas are moved at right angles :—

(*a*) 2 sq. in. through 4 in. ?

(*b*) 144 sq. in. through 12 in. ? (*i.e.* 1 sq. ft. through 1 ft.). *How many cubic inches are there in* 1 *cu. ft. ?*

(*c*) 9 sq. ft. through 3 ft. ? (*i.e.* 1 sq. yd. through 1 yd.). *How many cubic feet are there in* 1 *cu. yd. ?*

(*d*) 100 sq. cm. through 10 sq. cm. ? (*i.e.* 1 sq. dm. through 1 dm.).

How many cubic centimetres (c.c.) *are there in* 1 *cu. dm. ?*

On the Continent you do not buy milk by the pint or quart, but by the *half-litre* or *litre*. Fig. 52 shows a flask which holds a *litre* when filled with liquid up to the mark on the neck. By its side is a hollow metal box which holds a cubic decimetre.

Fill a litre flask up to the mark with water and pour it into a cubic decimetre box. The latter is just filled. **Thus a litre is a cubic decimetre, or 1000 c.c.**

On the Continent petrol is measured in litres instead of in gallons.

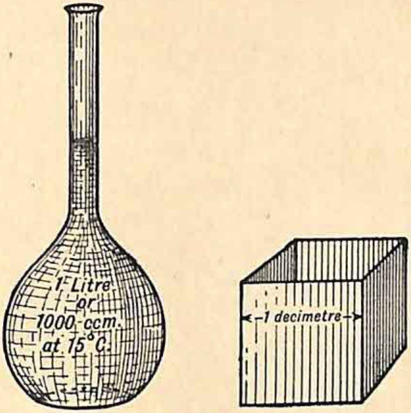
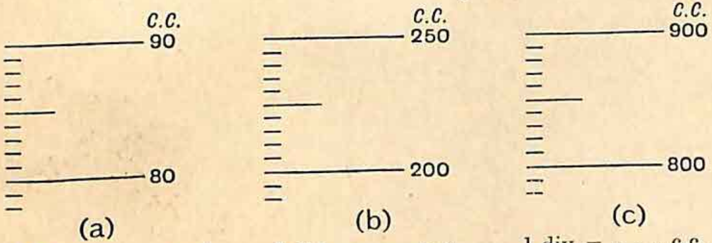


FIG. 52.

Measuring cylinders are often marked in cubic centimetres. You should now examine several.

Fig. 53, (*a*), (*b*), (*c*), shows some of the graduations marked on common measuring cylinders. *What is the value of one graduation in each case?*



1 div. = . . . c.c. 1 div. = . . . c.c. 1 div. = . . . c.c.

FIG. 53.

What is the value of

(i) 2·5 divisions in (*a*) ?
(ii) 3·0 ,, (*b*) ?
(iii) 2·5 ,, (*c*) ?

Make similar sketches for as many differently marked measuring cylinders as you can find. State the value of one graduation under each sketch.

Pour some water into a 50-c.c. or 100-c.c. measuring jar. The water curls up the jar at the edges. The curved surface is called the meniscus. Draw the shape of the surface. In measuring the volume of water your eye must be level with the bottom of the meniscus as shown in fig. 54. If the eye is above the level of the bottom of the meniscus the reading will be too high; if the eye is below, the reading will be too low. Obtain a pint measure.[1] Fill it with water to the pint mark and pour carefully into a 100-c.c. measuring cylinder. Fill this to the 100-c.c. mark as many times as you can, and so find the number of cubic centimetres in 1 pint. Repeat this several times. Record each result and find the average.

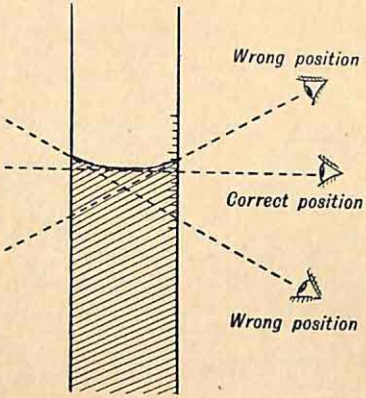


FIG. 54.

Number of cubic centimetres in 1 pint:

(*a*) . . ....
(*b*) . . ....
(*c*) . . ....
(*d*) . . ....
Total . ....
Average ....

Now make a graph to convert gallons into litres. (Show gallons up to 5 and litres up to 25.) This would be useful on the Continent if you were motoring and your petrol tank indicator registered gallons.

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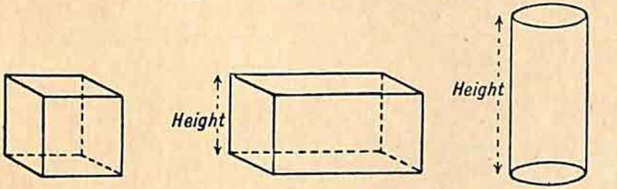
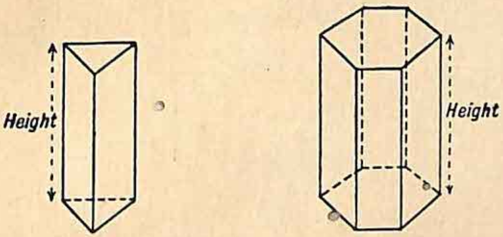
[1] An aluminium pint or quart measure will do for this.

Volumes of Prisms.—A right prism may be regarded as a solid which is obtained by moving a plane area at right angles to itself. It is named according to the face which is moved to map out the prism. Several prisms are shown in fig. 55. In each case say which face must be moved to map out the prism.



Square Prism or Cube **Rectangular Prism** **Circular Prism or Cylinder**



Triangular Prism **Hexagonal Prism**

Fig. 55.—Some prisms

If the area of the end is 2 sq. in. and the distance between the ends is 4 in., what is the volume of the prism ?

The volume of a prism is the area of the face moved × perpendicular distance through which it moves.

Exercise 1—To find the Volume of a Regular Prism (by calculation) in cubic centimetres and cubic inches

Tabulate measurements as shown. All the calculations connected with the exercise should be done below the table.

Name of prism	Face which determines prism	Area of this face	Corresponding perpendicular distance	Volume	$\frac{\text{c.c.}}{\text{cu. in.}}$
Rectangular prism.	Rectangle	sq. cm.	cm.	c.c.	
		sq. in.	in.	cu. in.	
Triangular prism.					
Cylinder.					

What does the last column tell you ?

Exercise 2—To compare the Volume of a Pyramid [1] with that of the corresponding Prism

This may easily be done by using a hollow pyramid and the corresponding hollow prism.

By the corresponding prism is meant the prism with the same base and of the same height as the pyramid.

Fill the hollow pyramid with sand and pour the sand into the corresponding hollow prism. How many pyramidfuls are required to fill the prism? The cone is a pyramid, the base of which is made up of an indefinite number of sides (*i.e.* is a circle). Compare its volume with that of the corresponding cylinder. How then would you find the volume of a pyramid ?

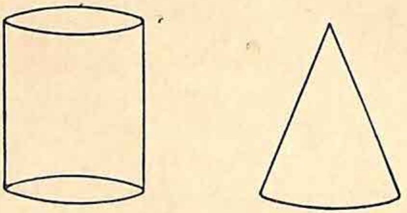


FIG. 56.

That a cone is one-third the volume of a cylinder of the same base area and height was first discovered by a Greek, Democritus, as long ago as the fifth century B.C.

Exercise 3—The Volume of a Sphere

(a) To compare the volume of a sphere with the volume of a cylinder just large enough to enclose the sphere. Put the wooden sphere into the glass cylinder and notice that the top of the sphere is just level with the top of the cylinder, also that the sphere just touches the sides of the cylinder (fig. 57).

---

[1] *Pyramid*—The vertical height of the Great Pyramid at Gizeh was named by the Egyptians "pir-em-us," hence the Greek form *pyramis*, pl. *pyramides* (Herod.), used unaltered in the English of Sandys (1615), from which the singular, "pyramid," was formed.

Holding the wooden sphere down, pour water into cylinder until just full; carefully remove the sphere (avoid spilling any water).

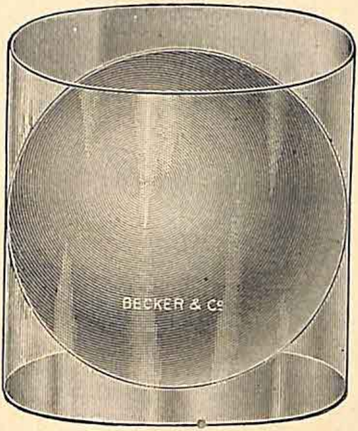


FIG. 57.

Measure in centimetres the height of the water inside the cylinder. Measure in centimetres the inside height of the cylinder.

What fraction of the volume of the whole cylinder is the volume of the water?

The water occupied that part of the cylinder not occupied by the sphere. *What volume therefore of the cylinder was occupied by the sphere?*

Calling the radius of the sphere r, find a formula for (a) the volume of the cylinder, and hence (b) the volume of the sphere.

Archimedes (287–212 B.C.), the greatest of the Greek mathematicians and experimenters, first discovered that the volume of a sphere is two-thirds that of the circumscribing cylinder. He considered this the greatest of his many achievements.

(*b*) Observe the hollow cone and the two hollow hemispheres. What do you notice about the dimensions? Fill

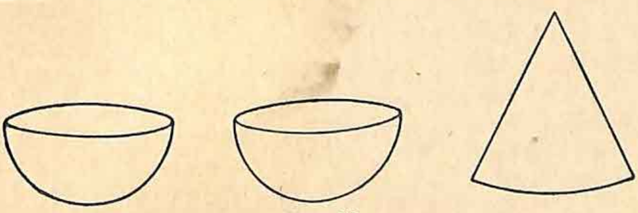


FIG. 58.

the hollow cone with sand and find how many fillings are necessary just to fill the two hemispheres.

Calling the radius of the sphere r, find a formula for (a) the volume of the cone, (b) the volume of the sphere.

Exercise 4—The Area of the Surface of a Sphere

Describe and sketch the apparatus supplied (fig. 59).[1]

Measure the length of the black square and find its area.

Inflate the rubber discs until you form a sphere. Again measure the sides of the square and find its area.

How many times bigger is the square after inflating ?

How many times does the area of a circle divide into the area of the surface of a hemisphere of the same radius ?

Now write down a formula for the area of the surface of a sphere in terms of the radius r.

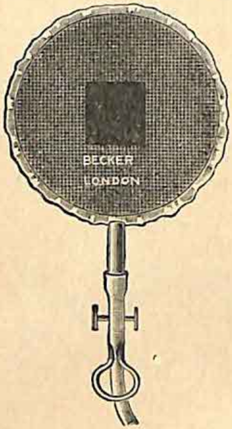


FIG. 59.

Exercise 5—To use the Area of the Surface of a Sphere as a means of determining the Volume of a Sphere

A sphere may be supposed to consist of a large number of small pyramids or cones having their bases in the surface and their vertices at the centre.

If the bases are very small they may be regarded as plane figures. Then the height of each pyramid becomes equal to the radius and the volume of the sphere will be the total volume of the pyramids. Suppose the area of the base of each pyramid $= A$, then volume $= A \times \frac{1}{3}r$.

The volume of all the pyramids will be (the sum of all the bases) $\times \frac{1}{3}r$.

But the sum of all the bases equals the area of the surface of the sphere $= 4\pi r^2$. Hence the volume of the sphere $= \frac{4}{3}\pi r^3$.

Find the surface area and the volume of the given sphere. Tabulate results.

---

[1] *Note*—This apparatus consists of two flat rubber discs arranged so that they may be inflated to give a sphere.

CHAPTER VI

EXPERIMENTS ON DENSITY

To Set up and Calibrate a Steel Spring—The making of a spiral spring is an expert's job and too difficult to attempt in class. Springs suitable for our experiment may be bought for a few pence each.[1] The coils will probably be touching each other, as in fig. 60, and will require some force to separate them. The spring should first be pulled out carefully, extending it until, when released, the coils are separated a little. The two last turns should then be pulled out and heated in a flame, after which they will be soft enough to straighten and a loop can be made on the end. Fit up the spring so that it hangs through a cork in a glass tube, as shown in fig. 61. The lower cork may be fastened into the tube when the spring is not in use. A strip of paper should be pasted along the glass tube, on which the calibration marks may be put.

Fig. 60.

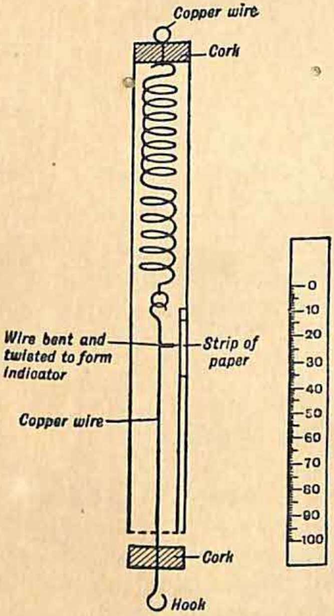


Fig. 61.

First put a mark 0 on the paper opposite the indicator when the spring is hanging freely with no weights attached. By means of cotton attach weights, increasing by 10 grm. at a time, and mark the paper opposite the indicator with the number of grams which have been added.

---

[1] Messrs Philip Harris, Ltd., supply springs which are suitable for 0–100, 0–250, 0–500 grm.

These marks will be equidistant from each other, showing that *the extension of the spring is proportional to the load.* It will be convenient to set up springs reading from 0–100, 0–250 grm. Scale pans made from lids of tin cans may be put on to the hook when required. You should subdivide the divisions so that the spring-balance reads in steps of one or two grams.

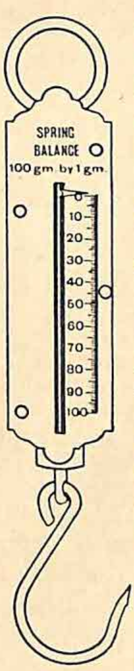


FIG. 62. A spring-balance

As you are aware, spiral springs are used in everyday life for other purposes than weighing. When a spring is pulled out or compressed its resistance is proportional to the extension or the compression. Spiral springs are used to reduce shocks in the driving wheels of a locomotive, and you will find many examples of their uses on any motor-car.

For the following exercises the spring-balance you have made is suitable, or a 0–100 grm. spring-balance reading in steps of 1 grm., such as is shown in fig. 62. This should be treated with care, and occasionally the brass tube should be oiled.

To determine the Weight of 1 c.c. of Water—In performing this experiment you will use three different types of apparatus for measuring the volume of the water. All of these pieces of apparatus will be used many times in your science work, and it is important that you should know how to use each one. They are—

1. *The Graduated Cylinder*—This was dealt with in the last chapter.
2. *The Burette* (fig. 63)—Examine a burette. In what way does *it differ from a graduated cylinder* ? In measuring out a volume of water from a burette proceed as follows: Pour some water into the burette until its level is above the top graduation mark, and let water out until the bottom of the meniscus is level with the top graduation mark. *What do you observe about the tube below the tap ?* You can now run out any volume of

water between 0 and 50 c.c. Care must be taken not to run out the water below the bottom graduation mark.

3. *The Pipette* (fig. 64)—This is an instrument for measuring a definite quantity of liquid. Unlike the burette, a pipette can only measure one definite volume. Pipettes are made in different sizes to measure 1 c.c., 2 c.c., 5 c.c., 10 c.c., 20 c.c., 25 c.c., 50 c.c., and 100 c.c. A certain amount of practice will be required before you can control the liquid in a pipette. Hold the pipette as shown in fig. 64. Place the pointed end under the surface of some water in a beaker and suck air out of the pipette until the water rises above the mark in the stem. Quickly slip the first finger over the end of the pipette as you remove it from your mouth. By carefully moving the first finger from side to side (or rotating the pipette, whichever is easier to you) you will learn how to control the flow

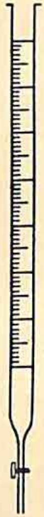


Fig. 63.
A burette

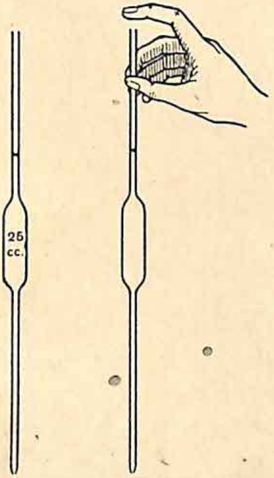


Fig. 64.
A pipette

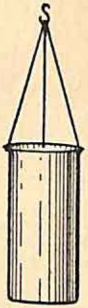


FIG. 65.

of the water. The water should be allowed to run out until the bottom of the meniscus is level with the mark on the stem. When delivering the water from a pipette just allow it to run out into a weighed tin can (see fig. 65). On no account should you blow it out. You should now be able to take a known volume of water by three distinct methods and find the weight of 1 c.c., tabulating your results as follows :—

Results :

Vessel used	Volumes			Weight			Weight of 1 c.c.
	1st reading	2nd reading	Vol. of water	Tin can	Tin can and water	Water	
	c.c.	c.c.	c.c.	grm.	grm.	grm.	grm.
Measuring cylinder .							
Burette . .							
Pipette . .							

Which of these measuring vessels will be the most accurate, and why ?

The Scientific Standard of Weight—The French scientists, of whom you read in Chapter III, decided to call the weight of 1 c.c., or 1 millilitre, of water 1 grm.[1] This is the standard used in scientific work all over the world.

To find the Weight of 1 c.c. of Various Metals—You are provided with several cubes of metal, each of 2 cm. side. Find the weight of these, and work out the weight of 1 c.c.

Results :

Metal	Volume	Weight	Weight of 1 c.c.
	c.c.	grm.	grm.
Iron . .			
Tin . .			
Copper .			

---

[1] At a temperature of 4° C. in the latitude of Paris.

Density—*The weight*[1] *of unit volume of a substance is called its density.*

$$\text{Density (D)} = \frac{\text{Weight (W)}}{\text{Volume (V)}} \quad \text{or} \quad D = \frac{W}{V}.$$

In the metric system the density of a substance is expressed in grams per cubic centimetre, in the English system in pounds per cubic foot. As 1 cu. ft. of water weighs 62·5 lb., the density of water, in English measure, is 62·5 lb. per cubic foot.

Now complete the following table:—

Substance	Density (metric system)	Density (English system)
Water . .	1 grm. per c.c.	62·5 lb. per cubic foot.
Aluminium .	2·7 ,, ,,	
Iron . . .	7·7 ,, ,,	
Copper . .	8·9 ,, ,,	
Lead . .	11·3 ,, ,,	

When the term **relative density**[2] is used for solids and liquids, it means the density relative to water as standard, *i.e.*

$$\text{Relative density} = \frac{\text{Density of substance}}{\text{Density of water}},$$

$$= \frac{\text{Weight of substance}}{\text{Weight of same volume of water}},$$

and is a mere number. This number is the same as that expressing the density in grams per cubic centimetre.

The density of a gas is usually expressed relative to the lightest gas known, hydrogen. Thus the *relative density* of oxygen is 16, that of helium 2, that of nitrogen 14.

The Use of the Relative Density Bottle—Examine the bottle carefully and make a drawing of it. Why do you think the stopper has a hole through it?

It is quite simple to make a fairly accurate and cheap density bottle for yourself out of a scent bottle with a ground-glass stopper by filing a groove on the side of the stopper. This bottle can be used for determining the relative density of liquids (and also of solids in the form of insoluble powders).

---

[1] *Note*—More accurately, density is the *mass* of unit volume, but it is well to avoid the term "mass" at this stage.

[2] Sometimes called *specific gravity*.

(*a*) **To find the Relative Density of Liquids by Density Bottle**—Weigh a clean, dry bottle. Fill it with the given liquid, being careful to avoid the presence of air-bubbles. Weigh again. Pour the liquid back into the store bottle; wash the bottle thoroughly and fill with water. Dry the outside of the bottle and weigh again. From these weighings you can determine the relative density.

Record results as follows :—

Liquid used : Methylated Spirit

Weight of bottle ......
Weight of bottle full of liquid ......
Weight of liquid ......
Weight of bottle full of water ......
Weight of a volume of water equal to that of liquid ......

$$\text{Relative density} = \frac{\text{Weight of liquid}}{\text{Weight of same volume of water}} \ldots\ldots$$

Repeat, using other liquids or solutions, and record results in the same way as shown above.

(*b*) **To find the Relative Density of Lead Shot and Sand by Density Bottle**—*Use the same bottle as in last exercise. Its weight when empty and its weight when full of water are therefore known.*[1]

Half fill the dry bottle with lead shot. Weigh, keeping the shot inside the bottle; fill up with water and weigh again.

Record as follows :—

Solid : Lead Shot

(1) Weight of bottle ......
(2) Weight of bottle and shot ......
(3) Weight of lead shot ......

---

[1] *Note*—It will be found advisable to number the bottles and stoppers and allocate a particular number to a given pair of pupils.

(4) Weight of bottle full of water ......
(5) Weight of bottle full of water and lead shot ......
(6) Weight of bottle and lead shot inside and filled up with water ......
Why is (6) less than (5) ?
(7) Therefore the weight of a volume of water equal to that of the lead shot = ...
(8) Therefore relative density = ...

Repeat with sand, after drying the bottle as thoroughly as you can by shaking. (If not required in the same lesson, the bottle may be dried in the oven before next class.)

Other Suggested Experiments

(1) Find the density of lead shot. Weigh out a large number. Transfer these to a burette containing some water and so find the volume.

(2) Obtain a hollow cube 3 in. × 3 in. × $3\frac{1}{4}$ in. high, which can be suspended from a spring-balance by means of attached wires shown in fig. 66. Note the weight. Fill with water to a depth of 3 in. and weigh again. The volume of water is $\frac{1}{64}$ cu. ft. Find the weight of a cubic foot of water. A spring-balance reading to 2 lb. in ounces is suitable for this experiment.

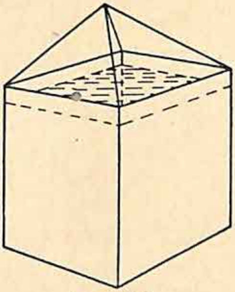


Fig. 66.

(3) If a large spring-balance is available, weighing, say, to 15 or 20 lb. by $\frac{1}{4}$ lb., the density of sand can be found as follows :—

Weigh first a bag of sand, then a large stoppered bottle full of water, together with the bag of sand. Then empty the sand into the bottle and fill up with water. Weigh again (including the bag). The difference between the last two weighings is the weight of water displaced by the sand. Since 62·5 lb. of water occupy 1 cu. ft., the volume of the sand can be calculated in cubic feet, and then the density in pounds per cubic foot.

(4) Find the weight of one pint of water, and from it calculate the weight of a gallon in pounds.

CHAPTER VII

BUOYANCY. THE PRINCIPLE OF ARCHIMEDES

Buoyancy—Attach a large iron weight [1] to a cord and suspend it on the hook of a spring-balance (fig. 67*a*). Raise a bucket of water underneath and watch the indicator of the balance as the weight is gradually immersed. *What do you notice?*

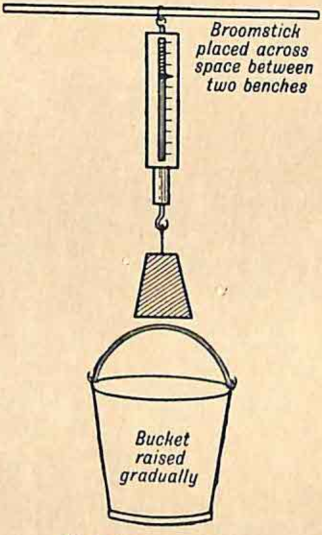


FIG. 67*a*.

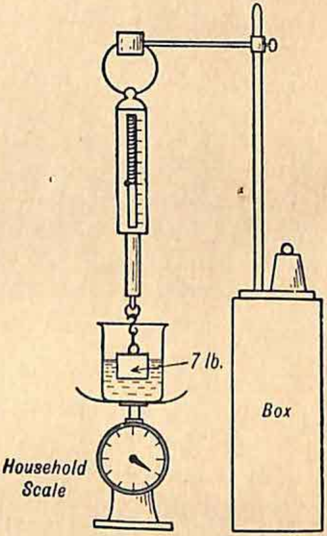


FIG. 67*b*.

When the weight is being immersed can you lift the bucket as easily as you could before? Now repeat the experiment, using the apparatus shown in fig. 67*b*.

These experiments illustrate a fact that you must have noticed when floating on water—the water appears to push you up. *Thus objects which are wholly or partly immersed in*

---

[1] A 14- or 28-lb. weight on a spring-balance reading to 30 lb. will do well.

water appear to weigh less than in air. This tendency of liquids to support part of the weight of objects immersed in them is called *buoyancy.* It is this buoyancy which supports a ship.

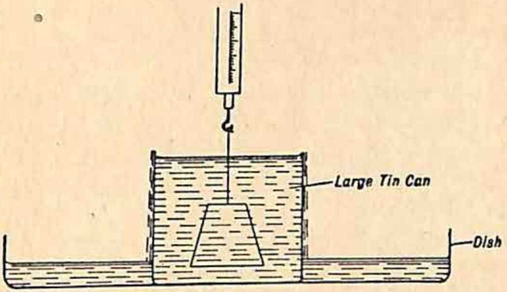


FIG. 68.

To discover the Law of Buoyancy—(1) Fill a bucket or a large tin can to the brim with water and let it stand in a large shallow dish; a roasting-tin will serve quite well. Hang a large iron weight from a spring-balance; note its weight. Now slowly lower it into the water until it is completely immersed. Note the reading on the spring-balance. Record the loss in weight. The iron weight has displaced its own volume of water, and the water displaced has been caught in the tin. Remove the weight carefully, so that no more water splashes over into the dish. Remove the bucket carefully. Pour the water from the dish into a weighed tin can. What is its weight? What was the apparent loss in weight of the piece of iron? *What conclusion do you draw from this experiment?*

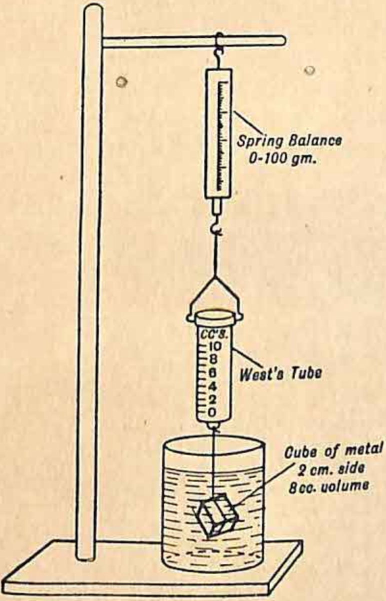


FIG. 69.—West's apparatus

(2) Fit up the West's apparatus[1] shown in fig. 69. The

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[1] Obtainable from Becker & Co., or Philip Harris & Co.

glass tube is graduated in cubic centimetres. First note the reading of the spring-balance with the cube of 8 c.c. volume suspended in air. Then lower the cube into the water. Note the new reading of the balance. Now carefully add water to the graduated tube by means of a pipette until the reading of the spring-balance is the same as at first. What *volume* of water have you added? What *weight* of water has been added? What volume of water is displaced by the cube? What is its weight?

Repeat the experiment, using 2 cm. cubes of several metals in turn. Iron, aluminium, copper, lead, tin, and zinc may be used by various members of the class and the results tabulated on the blackboard thus:

Metal	Volume of water displaced	Spring-balance readings		Apparent loss in weight	Weight of the volume of water which restores the balance
		Metal in air	Metal in water		
	c.c.	grm.	grm.	grm.	grm.

The experiments (1) and (2) show that *the upthrust (or buoyancy) of water on an immersed solid is equal to the* **weight** *of the water displaced.*

You naturally ask: *Does this apply to other liquids besides water?* Try the experiment with methylated spirits and with brine in turn, *using the same liquid in beaker and graduated tube.*

Results:

(1) Liquid used	(2) Metal	(3) Volume of liquid displaced	(4) Spring-balance readings	(5)	(6) Apparent loss in weight	(7) Weight of the volume of liquid which restores the balance
			Metal in air	Metal in liquid		
Methylated spirit .		c.c.	grm.	grm.	grm.	grm.
Brine .						

Can you suggest a reason for columns (3) and (7) not reading the same number as they did in the case of water ?

The experiments suggest that—

The upthrust of any liquid on an immersed solid is equal to the *weight* of liquid displaced. Its application to gases will be dealt with in Chapter VIII.

This is known as the **Principle of Archimedes,** after its discoverer.

The story goes that Hiero, King of Syracuse, provided a jeweller with some gold to make a gold crown for an offering to the gods. When the crown was delivered, the King suspected that the goldsmith had alloyed the gold with silver, and so had cheated the King of some of the gold. Hiero asked Archimedes to find out if this was so. Whilst thinking over the problem Archimedes is said to have noticed, when in a bath, that his limbs were buoyed up, and this gave him the idea of making experiments to discover the extent of this buoyancy. He is said to have been so elated that he ran home through the streets, forgetting to dress himself, shouting out "Eureka!" (I have found it!). Although he was known to be absent-minded, it is more than likely that this is a fable.

Archimedes was a very remarkable man. He was a great mathematician, and one of the first scientific experimenters. When he was an old man the Romans besieged Syracuse, and Archimedes applied his knowledge in the construction of catapults and machines for dropping heavy weights on the enemy ships as they sailed beneath the walls. It is said that one of his contrivances grappled the prow of ships, lifted them clean out of the water, and then let go so that they were swamped. The Romans were so much afraid of him that the Greeks had only to put a piece of rope or a plank over the walls to make them flee, crying "Here he comes!" Eventually the Romans took the city, but their general admired Archimedes so much that he gave orders to save the great man at all costs. It is said that Archimedes was deep in a mathematical problem, drawing figures in the sand, and did not notice the approach of a Roman soldier, who trod on his diagram. "Stand away, fellow, from my diagram," Archimedes is reputed to have said, and pushed the man off. Enraged and not knowing who he was, the soldier slew him.

Experiments using Archimedes' Principle—Archimedes' Principle gives us an easy means of finding the volume of any solid which sinks in water. Suppose the solid appears to lose 20·5 grm. in weight when completely immersed in water. Then 20·5 grm. is the weight of water displaced, and since every gram of water occupies a volume of 1 c.c., the volume of the solid is 20·5 c.c.

The relative density[1] of a substance is

$$\frac{\text{The weight of the substance in air}}{\text{The weight of an equal volume of water}},$$

i.e.

$$\frac{\text{The weight of the substance in air}}{\text{The upward thrust of \textit{water} on the substance when totally immersed}}.$$

For instance, 1 c.c. of copper weighs 8·9 grm.; 1 c.c. of water weighs 1 grm.

The relative density of copper is thus $\frac{8{\cdot}9}{1{\cdot}0}=8{\cdot}9$.

Note that this is the same **number** *as the density expressed in grams per cubic centimetre.* Thus if we find the relative density of a substance, we know its density in grams per cubic centimetre.

You should now *find the relative density of various solids which sink in water.*

Use any kind of spring-balance, graduated in lb. or grm., and use various sizes of solids from the cubes already used, and large lumps of coal, etc. Before trying porous substances, such as a brick or a piece of chalk, give them a coat of varnish or cellulose[2] so that they do not become waterlogged.

Arrange your results thus:

---

[1] Sometimes called specific gravity.

[2] Celluloid dissolved in amyl acetate will do.

Substance	Weight in air	Weight in water	Weight of water displaced	Relative density	Density
Glass .	25·5 grm.	15·0 grm.	10·5 grm.	2·4	grm./c.c. 2·4
Iron .	56 lb.	48 lb.	8 lb.	7·0	7·0

To find the Relative Density of a Liquid—Find the apparent loss in weight of a large glass stopper or pebble (*a*) in the given liquid (brine or methylated spirits), (*b*) in water.

*Are the **volumes** of liquids displaced the same?*

*Are the **weights** of liquids displaced the same?*

(Refer to footnote on p. 62.)

Results :

Liquid	Weight of stopper			Weights of displaced		Relative density of liquid
	(*a*) in air	(*b*) in water	(*c*) in liquid	water	liquid	
Salt solution .						
Methylated spirits .						

To find the Relative Density of a Body which Floats, using Archimedes' Principle—(*a*) Attach a piece of sheet lead to a

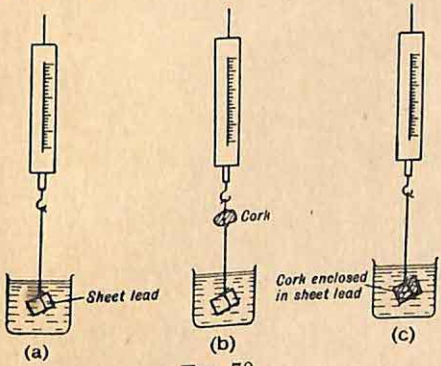


FIG. 70.

fine wire. Weigh it hanging in water (fig. 70) and record the reading.

(*b*) Twist the wire round the cork as shown in (*b*). Read the spring-balance again. *What is the weight of the cork in air?*

(*c*) Untwist the wire, wrap the cork in the sheet lead and immerse both in water. Read the spring-balance. *What is the upward thrust of the water on the cork?* Find the relative density.

Results:

Readings

(*a*) Weight of lead in water = 67·0 grm.
(*b*) Weight of lead in water and cork in air = 70·0 ,,
(*c*) Weight of lead in water and cork in water = 51·0 ,,
Weight of cork in air = 3·0 ,,
Upthrust of water on cork = 19·0 ,,
Therefore relative density of cork = 0·15 ,,

Does it matter what size of lead foil is used in this experiment?

CHAPTER VIII

FLOTATION

WEIGH a large block of wood in air. Allow it to float on the surface of some water in a bucket so that the string is slack. *What does it appear to weigh now? How much of its weight is the water supporting?*

Prepare the apparatus shown in fig. 68 (p. 63), the large can being full of water to the brim, and the shallow dish being dry. Gently lower the block into the water until it floats. Weigh the water which overflows and compare its weight with that of the block of wood.

This experiment shows that

A floating body displaces its own weight of liquid, *i.e.* the upthrust of a liquid on a floating body is equal to the weight of the latter.

When you read that a ship has a displacement of 20,000 tons, this means that when loaded so as to be immersed to a mark called the Plimsoll line the ship and cargo weigh 20,000 tons. The Plimsoll lines are shown in fig. 71. In fresh water the

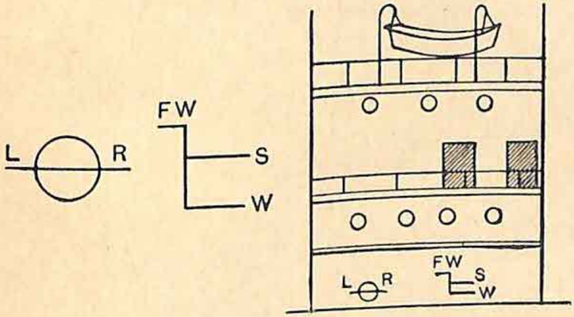


FIG. 71.—The Plimsoll line

LR = Lloyd's Register
FW = Fresh water
S = Summer
W = Winter

ship may be loaded so as to sink to FW. On reaching the sea the greater buoyancy will raise the ship to the mark S in summer and to W in winter. LR shows that the loadline has been fixed by Lloyd's Register of Shipping.

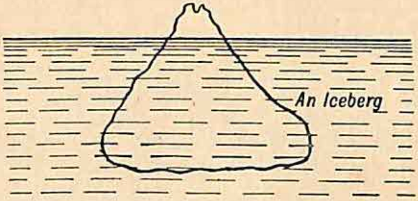


Fig. 72.

Icebergs—The density of ice is 0·917 grm. per c.c., that of sea-water is about 1·026 grm. per c.c. Thus ice will float, but with only a small fraction of its volume ($\frac{1}{9}$ approx.), above the water. It is the $\frac{8}{9}$ths immersed which makes an iceberg dangerous to a ship if it approaches too near.

Hydrometers — You are provided with a long rectangular piece of wood in one end of which is embedded a block of metal to make it float upright in water.[1] It is marked from this end in centimetres along its length. This can be used as a hydrometer. Note the depth which is immersed in water (h_1), in a liquid such as brine (h_2).

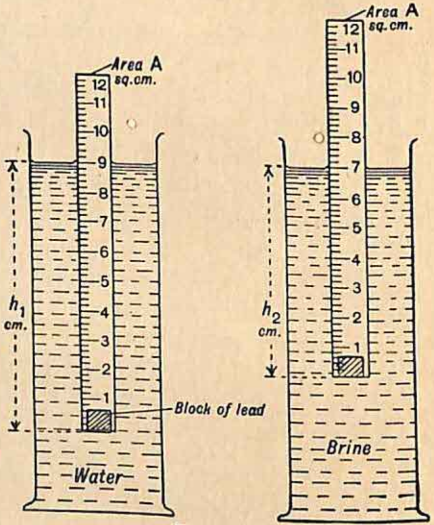


Fig. 73.

If A is the area of the end,

What is the volume of water displaced?

What is the **weight** *of water displaced?*

What is the volume of liquid displaced?

---

[1] *Note*—A test-tube with flattened end, loaded with lead shot, will do for this experiment. A piece of graph paper should be stuck inside.

These volumes are of equal weights (*why* ?). The density of the liquid is thus—

$$\frac{\text{Weight of liquid displaced by hydrometer}}{\text{Volume of liquid displaced by hydrometer}}$$

$$=\frac{\text{Weight of water displaced by hydrometer}}{\text{Volume of liquid displaced by hydrometer}}$$

$$=\frac{Ah_1}{Ah_2}=\frac{h_1}{h_2},$$

i.e.

$$\text{Density of } \textit{liquid}=\frac{\text{Depth in } \textit{water}}{\text{Depth in liquid}}.$$

Results :

Liquid	Water	Brine	Methylated spirits	
Depth hydrometer is immersed . .				
Density of liquid .				grm./c.c.

Hydrometers are of great practical use—you are probably familiar with the fact that hydrometers are used for finding the density of the acid used in accumulators. They are also used for testing milk. Hydrometers for the latter purpose are called *lactometers*. If milk is allowed to stand the cream rises to the top, and may be skimmed off. *Will the density of the skimmed milk be less or greater than that of unskimmed milk ?* Give reasons. The density of good quality cows' milk varies from 1·029 to 1·033. Lactometers are graduated in " degrees," from 15° up to 45°. The former corresponds to a density of 1·015, and the latter to 1·045. For accurate work

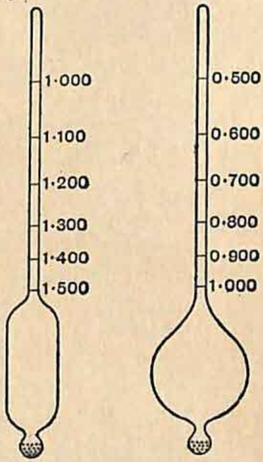


FIG. 74
Common hydrometers

hydrometers are made with a large bulb and a thin stem, allowing the divisions to be spaced out more. In the diagram two are shown, one for liquids of less and the other for liquids of greater density than water. Note that the divisions are not equally spaced.

Submarines and Balloons—Half fill a jar with water. Place in this a fresh egg. This sinks, showing that the weight of the egg is greater than the weight of an equal volume of water (fig. 75 (*a*)). Repeat, using a strong solution of common salt.

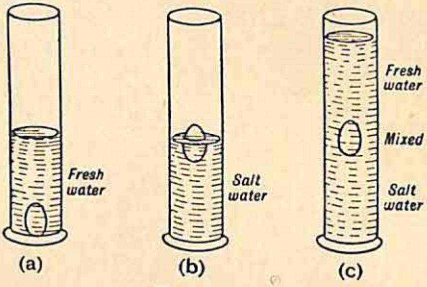


Fig. 75.

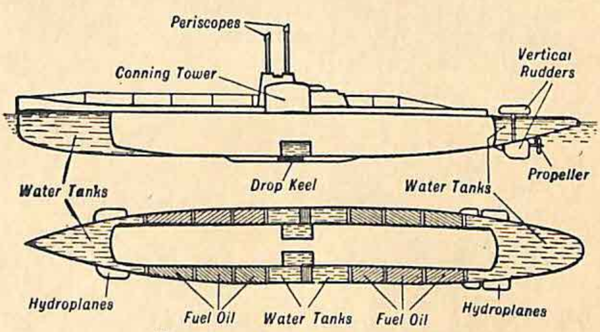
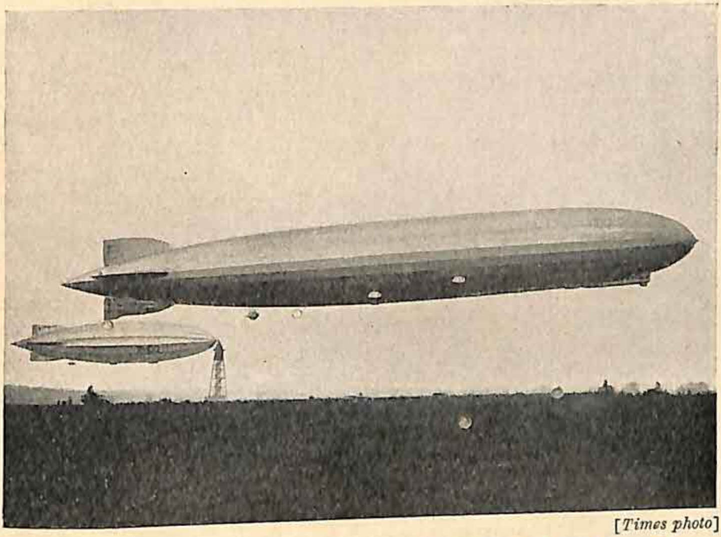


Fig. 76.—Submarine (section)

The egg floats. Why ? Now pour fresh water gently into the salt water. If you do this carefully the two liquids will only mix in the middle and the egg will float half-way (fig. 75 (*c*)). Evidently the weight of the egg is *then exactly equal to the weight of the liquid which it displaces.*

This simple experiment provides the clue to the questions:

(1) **How can a Submarine Remain under Water?**—If the submarine is floating, its weight is less than that of an equal volume of water. In order to sink it the weight must be increased. This is achieved by taking in water until the weight of the vessel is slightly more than that of the water displaced. When the submarine wishes to rise, some of the water is forced out by releasing compressed air.



[*Times photo*]

The Graf Zeppelin at Cardington. R 100 in the background

(2) **Why does a Balloon Rise?**—Balloons usually contain hydrogen, a gas which is only about a fourteenth as dense as air. The air exerts an upthrust on the balloon in exactly the same way as water exerts an upthrust on things immersed in it. If the upthrust is greater than the *total* weight of the balloon, including the fabric, basket, ropes, gas, and passengers, the balloon will rise. The air near the ground is compressed by the weight of the air above in very much the same way as air may be compressed in an air-gun. Thus the higher one goes the less dense the air becomes. *The*

balloon will stop rising when its total weight is exactly equal to that of the displaced air. If the balloonist wishes to rise higher, he drops ballast overboard, usually in the shape of sand; if he wishes to descend, he opens a valve and lets some of the hydrogen out of the gas-bag.

Airships are very much like balloons, except that they have motors attached to enable them to fly in all directions instead of drifting like balloons.

Hydrogen is a very inflammable gas, and the tragic loss of the great airship R 101 by fire in October 1930 has drawn attention to the necessity of replacing hydrogen by another gas, helium, which will not burn. Helium is twice as dense as hydrogen, but is still only about one-seventh as dense as air. It is a very rare gas, but quantities of it may be obtained in certain parts of the world, issuing from oil wells. Most people naturally think that as helium is twice as dense as hydrogen it will only lift half as much. Let us find out if this is correct by the following example:—

An airship has a volume of 10,000 *cubic metres. How much weight will it lift when filled* (a) *with hydrogen,* (b) *with helium?*

Density of hydrogen is 0·09 grm. per litre.
,, helium ,, 0·18 ,, ,,
,, air ,, 1·29 ,, ,,

Weight of air displaced by balloon
$= 1{\cdot}29 \times 10{,}000{,}000 = 12{,}900{,}000$ grm. $= 12{,}900$ kg.

Weight of hydrogen in the balloon
$= 0{\cdot}09 \times 10{,}000{,}000 = 900{,}000$ grm. $= 900$ kg.

Weight of helium in the balloon
$= 0{\cdot}18 \times 10{,}000{,}000 = 1{,}800{,}000$ grm. $= 1800$ kg.

Weight can be added until the total weight of the balloon is equal to that of the air displaced.

$\therefore$ Weight the hydrogen balloon will lift
$= 12{,}900{,}000 - 900{,}000 = 12{,}000{,}000$ grm. $= 12{,}000$ kg.

Weight the helium balloon will lift
$= 12{,}900{,}000 - 1{,}800{,}000 = 11{,}100{,}000$ grm. $= 11{,}100$ kg.

Thus for every 120 grm. or lb. that a hydrogen balloon will lift, 111 grm. or lb. will be lifted if filled with helium.

CHAPTER IX

EXPANSION BY HEAT

It is a matter of common observation that telegraph wires appear to be much tighter in cold weather than in hot weather, and every boy and girl knows that this is because they expand when heated and contract when cooled. Most substances, solids, liquids, and gases, expand when heated; a few, such as indiarubber, contract when heated. Some alloys have been made which do not expand when exposed to a high degree of heat. A knowledge of the expansion or contraction of substances when heated is of great importance to the engineer. For instance, the performance of a petrol engine depends on the pistons fitting the cylinder closely but not too tightly, and as both become very hot indeed when the engine is working, it is important that they should expand equally. To get some idea of the behaviour of solids, liquids, and gases when heated you should perform the following experiments.

(A) **Solids**

(1) Place a flat cake-tin on a tripod stand and heat by means of a Bunsen flame placed under the centre of the tin. Stand so that the tin is between you and a window and watch what happens (fig. 77). *Does the tin remain flat? Which part of the tin is the hottest? Why, then, does the tin buckle in the middle?* Turn out the Bunsen and pour a little cold water into the tin to cool it. Again note and explain what happens.

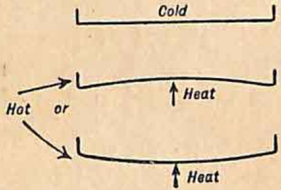


Fig. 77.

(2) Push one end of a knitting needle into a cork and fasten this firmly in a clamp so that the other end of the needle presses against the base of a retort stand (fig. 78).

Heat the needle by a Bunsen flame. *What happens?* Remove the Bunsen and watch what happens when the needle cools.

(3) Now support the needle so that its lower end is just touching the surface of some water in a beaker (fig. 79).

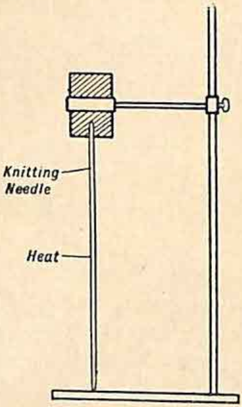


Fig. 78.

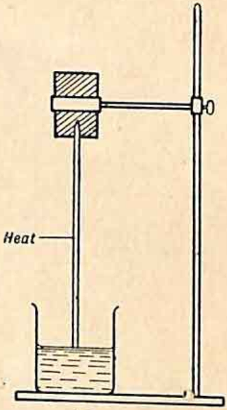


Fig. 79.

Heat the needle as before. *What happens to the end which is touching the water?*

In the first experiment the needle was prevented from expanding downwards. The forces exerted during expansion were sufficient to bend the needle. In the other experiment the needle was free to expand downwards, and it was plainly seen that the point went into the water when the needle was heated.

(4) **That enormous forces may be exerted by contracting metal is shown by the following experiment.** The rod R (fig. 80) is heated to redness in a fire and placed in position

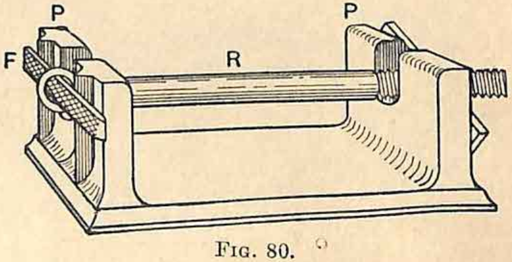


Fig. 80.

with a file F through the hole, and the nut on the other end is screwed tight. On cooling the file snaps.

(5) Fig. 81 shows a thin bar of brass riveted to a similar bar of iron. Hold by the wooden handle and pass several times through a flame. *What happens to the compound bar? Which expands most when heated under the same conditions, brass or iron?*

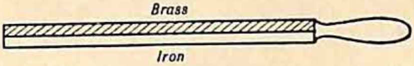


Fig. 81.

The experiments suggest that metals expand when heated, but different solids expand by different amounts when heated under the same conditions. An interesting application of the compound bar is in the calormeter fitted to the radiator of many motor-cars.

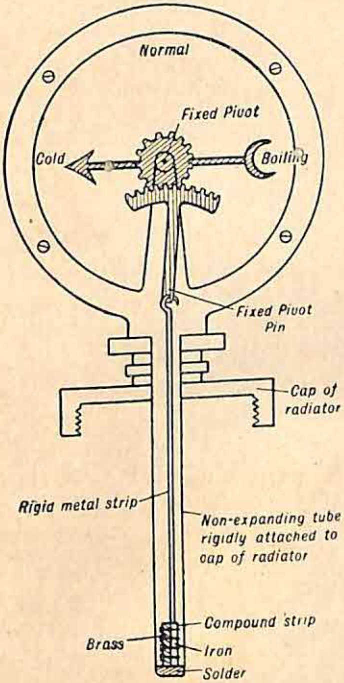


Fig. 82.—The calormeter

The Calormeter (fig. 82)—A short compound strip of brass and iron is soldered at one end to the bottom of a non-expanding case. The upper end is attached to a rigid strip of metal, which hooks round a pin connected to a lever as shown. When the temperature rises the compound strip bends, and this causes the lever to move about the fixed pivot. The cogs at the upper end of the lever move the cogs of the indicator, causing it to turn round. The working should be clear from the sketch.

(B) **Liquids**

(1) Fill a glass specimen tube about 3 in. by 1 in. diameter with cold water.[1] Fit a bung to it through which passes a

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[1] Coloured green by a little fluorescein so as to be visible.

piece of thick glass tubing of about $\frac{1}{16}$-in. bore. On pressing the bung into the specimen tube some of the water will rise up the tube to position A, which should be marked on the paper as shown in fig. 83. Holding the vessel by the neck, plunge it into some hot water. Keep your eye on the mark A.

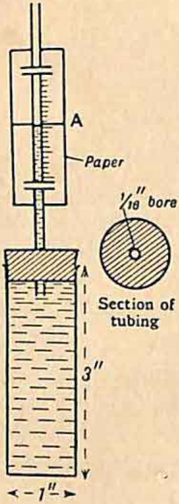

FIG. 83.

What happens (a) *immediately the vessel is in the hot water?*

What happens (b) *during the few minutes or so afterwards?*

Repeat the experiment two or three times to make sure you have observed everything. Start with fresh cold water each time.

(i) *Which became hot first, the vessel or the water inside it?*

(ii) *Did the vessel expand? Give reasons for your answer.*

(iii) *Which eventually expanded the more, the vessel or the water?*

After the vessel has been standing in hot water for some time plunge it into cold water. Make notes of all that happens, and give any explanation you can of what you observe.

Now fit up three specimen tubes of the same size with bungs, and glass tubes about 18 in. long and $\frac{1}{16}$-in. bore. Fill one with water, another with methylated spirits, and the third with mercury.[1] Insert the bungs and mark the levels A, B, and C (fig. 84). Place the specimen tubes carefully in a bowl of hot water and watch the levels until they have ceased to move.

Do equal volumes of these liquids expand equally when heated under the same conditions?

Arrange the liquids in order of their expansion, putting the most expansible first.

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[1] This should be done by the teacher. A wooden tray should be underneath to save the mercury in case of accidents.

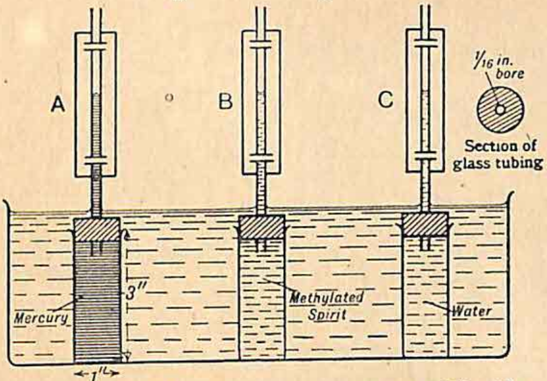

FIG. 84.—Experiment on expansion of liquids

(C) **Gases**

(1) Fit a flask of about 300 c.c. capacity with a bung through which passes a long tube (fig. 85). Take out the bung and draw some coloured water into the tube. Keep the tube horizontal and press the bung into the flask, which must be lying on its side, so that the water does not run out before the bung is in position. Arrange for the index to be just above the bung. Stand the flask on the bench. Place your warm hands on the flask. *What happens to the water in the tube, and why?*

Repeat, using a similar flask full of water. *Which expands most, air or water, when heated under the same conditions?*

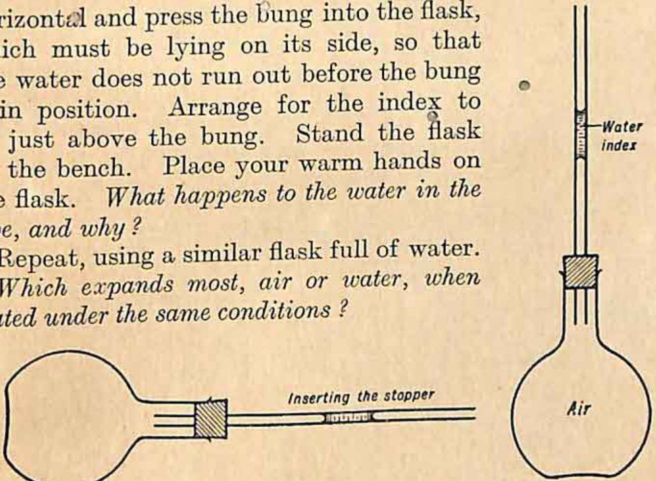

FIG. 85.—Experiment on expansion of air

(2) **Do equal volumes of different gases expand differently when heated?** A specimen tube 3 in. long and 1 in. diameter is fitted with a two-holed rubber bung through which passes glass tubes *a* and *b* as shown (fig. 86 (*a*) and (*b*).

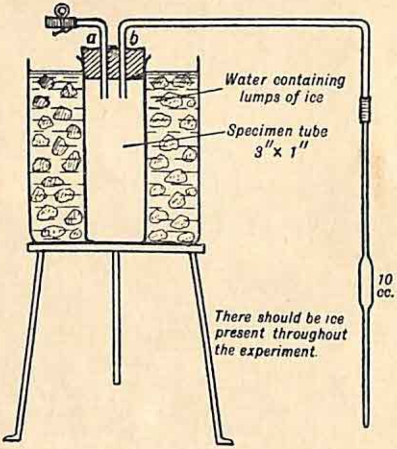
a
b
Water containing lumps of ice
Specimen tube 3″× 1″
10 cc.
There should be ice present throughout the experiment.

FIG. 86 (*a*).

The tube *a* is fitted with a rubber tube and a clip, and serves as a means of introducing any dry gas.[1] The tube *b* is connected to a 10-c.c. pipette. The specimen tube is filled with gas while it is standing in a container in which there is *ice cold* water. When sufficient gas has been passed into the specimen tube a beaker containing water is placed under the lower end of the pipette. The apparatus is now transferred into a can containing boiling water, *the end of the pipette being kept under water in a beaker during the transference.* When bubbles cease to pass from the end of the pipette, the apparatus is transferred back again to the ice cold water. It is then observed that the water from the beaker rises up the pipette to a certain point on the stem, which can be marked by gummed paper. Do the experiment with air, coal-gas, hydrogen, and oxygen, all carefully dried, and find out whether the water rises to exactly the same

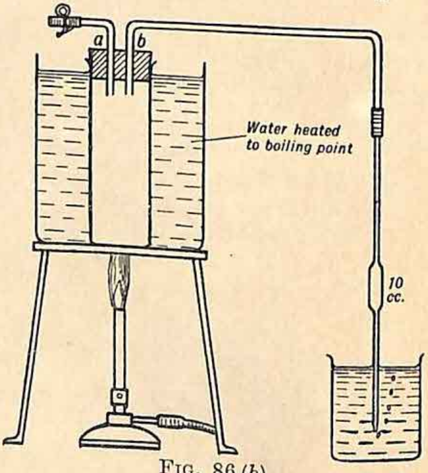

FIG. 86 (*b*).

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[1] Air and other gases should be dried by passing through a U-tube containing calcium chloride.

mark in each case. You should now be able to say whether ***equal volumes of different gases expand equally when heated under the same conditions.***

This behaviour of gases is most important and will be referred to again later.

Your experiments have taught you that:

(1) *As a rule, solids, liquids, and gases expand when heated, and that the expansion of gases is much greater than that of solids or liquids.*

(2) *That equal volumes of different solids and liquids expand by different amounts when heated under the same conditions; but*

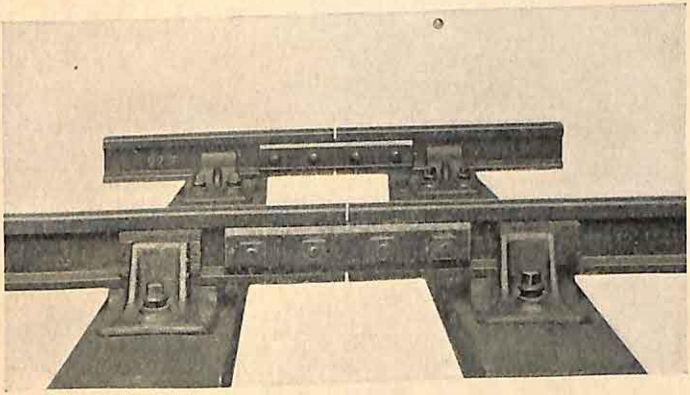
(3) *Equal volumes of different gases expand equally when heated under the same conditions.*

The last-mentioned fact is very surprising and also very important, as will be seen later on.

Some Practical Applications of Expansion by Heat

(1) Railway Lines

Next time you are on a railway station notice the joints where two rails join (fig. 87). (It is not advisable to get off the platform for this purpose!) You will observe a gap between the rails. The gaps are left to allow for expansion in



Portion of a railway track showing spaces left between rails for expansion
(Courtesy of the London and North-Eastern Railway)

summer. In a long railway, like the Canadian Pacific, which is 3000 miles long, total allowance for expansion adds up to over a mile. The connecting pieces (called fishplates) between the rails are fastened to the latter by bolts and nuts, and the holes in the rails through which these pass are oval in shape, and of a larger diameter than the bolts to allow play when expansion occurs. Spring washers allow the nuts to keep tight and yet allow for expansion.

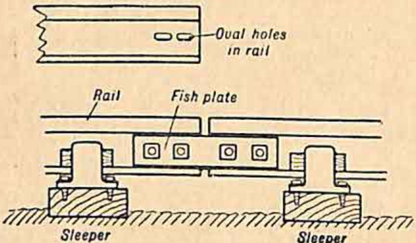


Fig. 87.

(2) Steam Pipes

Metal tubes for carrying steam are bent, as shown in fig. 88, to allow for expansion.

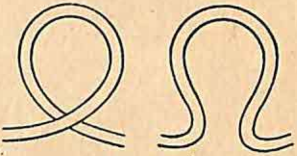


Fig. 88.

(3) Iron Tyres

In fitting iron tyres to wheels the tyre is made a little smaller than the wheel and is slipped on when red-hot. On cooling it grips tightly. In this way locomotive wheels are built up, and also the barrels of big guns.

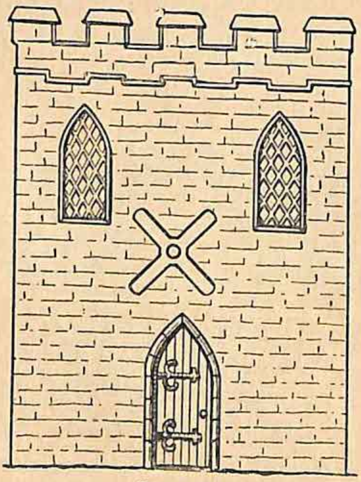


Fig. 89.

(4) Tie Rods

You have probably noticed two large iron cross-pieces on opposite outer walls of an old building (fig. 89). These are connected by a long iron bar passing through the building. The bar has been heated by surrounding it with cotton-wool soaked in oil or spirits, which is ignited. Whilst the bar is hot the bolts are screwed up tightly, and on cooling the contraction of the bar prevents the walls from leaning outwards.

(5) Tramway Lines

It is somewhat remarkable that tramway lines are welded together, for one would naturally expect them to buckle when exposed to the varying temperature of summer and winter. That this does not happen is probably due to the following reasons :—

(*a*) The rails extend some inches below the surface of the road, and as the road material is a bad conductor of heat, the temperature a few inches below the surface does not vary very much at different times of the year.

(*b*) The rails are embedded in concrete, which takes up any strain which is set up.

(6) Thermostats

The thermostat is an apparatus for maintaining a uniform temperature. The "**Regulo,**" which is a kind of adjustable

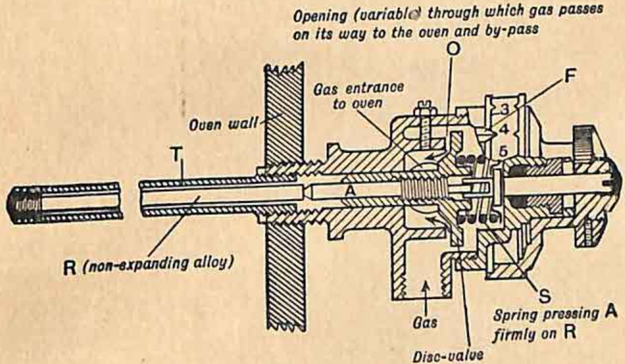

Opening (variable) through which gas passes on its way to the oven and by-pass
O
F
Gas entrance to oven
Oven wall
T
3
4
5
A
R (non-expanding alloy)
Gas
S
Spring pressing A firmly on R
Disc-valve

FIG. 90.—The "Regulo"

thermostat, has already been referred to (see p. 8). Its object is to adjust the supply of gas so as to maintain the oven at a steady temperature. The "Regulo" is shown in fig. 90. The outer tube T expands when heated, and as it does so it pulls rod R with it. The spring presses rod A on to R so that the opening O, through which the gas passes on its way to the oven, is reduced in size. The opening O may be set to different widths by turning the head and bringing the figures 1, 2, 3, 4, etc., opposite the pointer F. In the diagram the figure 4 is set opposite the pointer. As the gas burns and heats the oven, the tube expands and the opening O begins to close, diminishing the supply of gas. When a certain temperature has been reached, the disc-valve is prevented from closing further and the oven is maintained at a steady temperature. If this falls for any reason, such as opening the door, the tube contracts, allowing the valve to open and admit more gas. The rod R is of non-expanding alloy,[1] and rod A is kept pressed against it by the spring S. The disc-valve is attached to A, and when this is pushed down as the tube T expands the opening O is made smaller

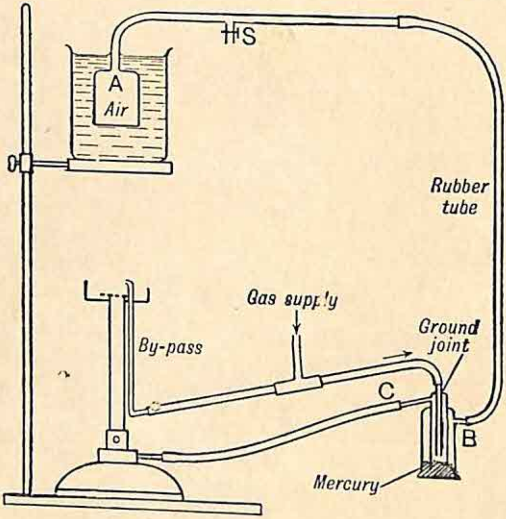


FIG. 91.—Thermostat (Baird & Tatlock)

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[1] *Invar*. An alloy of nickel, 35 per cent., and steel, 65 per cent., which is practically non-expanding with heat. This alloy finds great use in clock pendulums and in many other ways.

A thermostat which utilises the expansion of gases is shown in fig. 91. A metal vessel, A, containing air is connected to a special Bunsen which has a by-pass, through a glass vessel, B, as shown. The by-pass is always connected to the gas supply, but the Bunsen main supply has to pass through B by way of the central tubes and the side tube C. The screw S is unscrewed so that A is in connection with the air outside, and the Bunsen is lit. The vessel heated is stirred, and when it reaches the required temperature S is screwed down, so cutting off A from the outside air. If the temperature rises farther, the air in A expands and forces the mercury in B up the inner tubes, cutting off the main supply to the Bunsen. The Bunsen flame then goes out. As the temperature of the vessel falls, the air in A contracts and the mercury falls again, allowing the gas to flow once more. It is lit by the by-pass jet.[1]

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[1] The Bunsen is prevented from lighting back by a layer of gauze soldered on the chimney.

CHAPTER X

THERMOMETERS, AND HOW THEY ARE GRADUATED

IF ever you are ill, one of the first things the doctor does is to take your temperature by means of a small thermometer, the bulb of which is placed under your tongue for a minute or so. In the bulb of the thermometer is some of that interesting liquid, quicksilver or mercury. The bulb expands when it is warmed, but the mercury expands more than the glass and pushes its way along the very fine bore of the tube. When it has stopped expanding the doctor reads your *temperature* by observing the position the mercury has reached on the stem.

Common observation shows that if we put together two bodies at different temperatures the hotter body becomes cooler and the cooler body becomes warmer, irrespective of their sizes. The hotter of two bodies is said to be at the higher temperature. The commonest instrument for measuring temperature is the mercury thermometer.

FIG. 92.

The Mercury Thermometer—The making of a thermometer is a special art, and it is not advisable for young pupils to attempt it.

A bulb is blown on the end of a glass tube with a very fine bore. The bulb and part of the stem are filled with mercury. The bulb is put into a bath at a higher temperature than the thermometer is intended to read and then the stem is sealed. To graduate the thermometer we require two *fixed points*, which are marked by placing the thermometer in turn in substances at definite and unvarying temperatures. Nature has provided us with two such fixed temperatures, in the temperature at which *pure* ice melts and the temperature at which *pure* water boils *when the pressure* *of the surrounding atmosphere is normal, i.e.* 76 cm. of mercury. The level reached by the mercury in the stem is marked when the bulb is in (*a*) pure melting ice, and (*b*) in *steam* over water boiling under normal pressure. We immerse the thermometer in steam because this will be pure, whether the water is or not. The apparatus suitable for this purpose is shown in fig. 93.

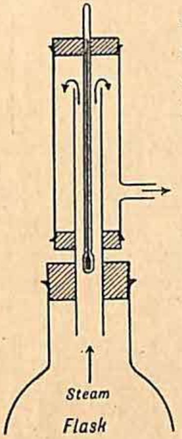

Fig. 93
Apparatus for marking the upper fixed point of a thermometer

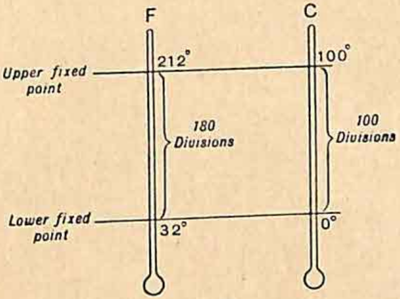

Fig. 94.

If the thermometer is to be graduated in Centigrade (100 steps) degrees, the lower fixed point is called 0° C. and the upper 100° C., and the space between is divided into 100 equal parts; if in Fahrenheit, these points are marked 32° F. and 212° F., the space between being divided into 180 equal parts. This is shown in fig. 94.

Experiments with Thermometers

1. **In the Neighbourhood of the Lower Fixed Point**—Fit up the apparatus shown in fig. 95.

(i) Hold the thermometer in the funnel and surround it with small pieces of broken ice. Note the reading, estimating to 0·1° C. Be sure you view the reading squarely.

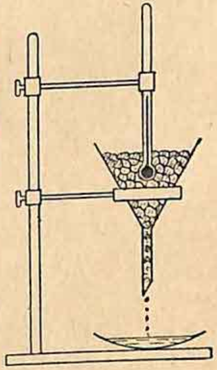

Fig. 95.

(ii) Now sprinkle a teaspoonful of salt on the ice and note the reading. Add still more salt.

Enter results as follows :—

Reading in pure melting ice = ...
" " ice and salt (*a*) = ...
" " " additional salt (*b*) = ...

What effect has the added salt on the temperature? To fix the position of the *lower fixed point* of a thermometer, a mark is made at the point reached by the mercury when in *pure* melting ice.

Why should the ice be pure?

If your thermometer reads *plus 0·5° C.* in melting ice, the reading requires a *correction of minus 0·5° C.* If it reads minus 0·2° C. the correction is plus 0·2° C.

What is the correction necessary for your thermometer at the lower fixed point?

2. **In the Neighbourhood of the Upper Fixed Point**—Fit up the apparatus shown in fig. 96.

Heat about 1 in. depth of water in flask until it boils. Arrange the *clean* thermometer to hang in the steam as shown. *Make sure it is firmly fixed in the cork and stand.*

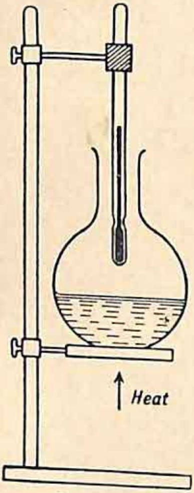

FIG. 96.

Reading—to be estimated to 0·1° C. :

(1) Note the reading with the thermometer bulb in the steam.

(2) Lower the thermometer into the water and note the reading again.

(3) Remove the thermometer and *wash it clean.* Add about a teaspoonful of salt to the water. Place the *clean* thermometer in the steam and note the reading.

(4) Lower the thermometer into the salt solution and read again.

Record results as follows :—

Readings of thermometer :

(1) In steam above boiling water = ... ° C.
(2) ,, boiling water = ... ° C.
(3) ,, steam above boiling brine = ... ° C.
(4) ,, boiling brine = ... ° C.

What do you notice about

(a) *The readings in the steam ?*
(b) ,, ,, ,, *boiling liquids ?*

The upper fixed point of a thermometer is marked by noting the level of the mercury when in *steam* over boiling water. *Why not in boiling water ?*

Boil some water in a round-bottomed flask. When it is boiling, remove the source of heat and put in a bung fitted with a thermometer. Turn the flask upside down as shown; place a basin underneath and pour cold water on the top. The water continues to boil, and the temperature falls lower and lower as you continue to pour on more water. The flask contained only water and steam, all the air having been driven out when the water was boiled before the bung was inserted. The steam was condensed by the cold water and the pressure above the water was reduced. The water boiled in an attempt to keep the space full of steam. *The experiment shows that water may be made to boil at different temperatures by altering the pressure, and shows the importance of specifying a fixed pressure in the definition of the upper fixed point.* The pressure specified is normal atmospheric pressure. (See Chapter XII.)

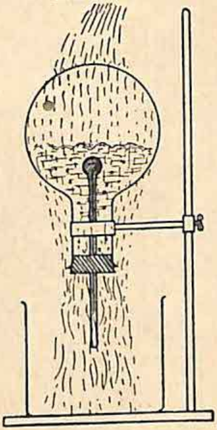

FIG. 97
Water boiling under reduced pressure

In a locomotive boiler the water boils under increased pressure and its temperature is well above 100° C.

An apparatus for testing the upper fixed point of a

thermometer was shown in fig. 93. The scientific instrument for this purpose is called a hypsometer, and is shown in fig. 98.

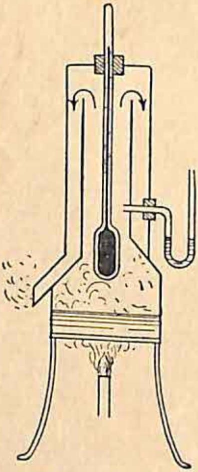

FIG. 98.—A hypsometer

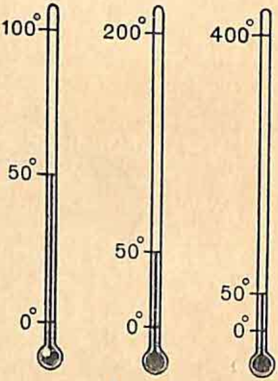

FIG. 99.

It may also be used to find the normal boiling-point of a liquid. Note that bulb and stem are immersed in the vapour above the boiling liquid.

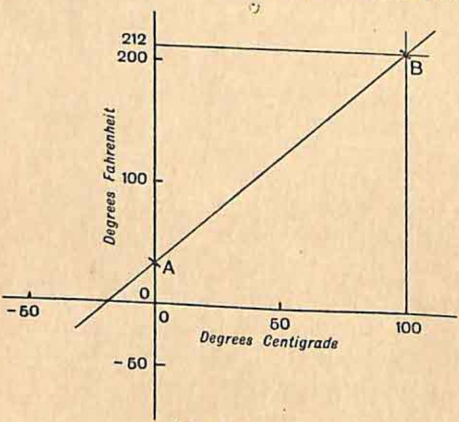

FIG. 100.

Fig. 99 shows three mercury thermometers graduated from 0° C. to 100° C., 400° C., and 200° C. respectively. The *bulbs* are all the same size. *How is it possible for these thermometers to have such different ranges?*

The normal boiling-point of mercury is 357° C., and yet mercury thermometers may be bought which are graduated to 400° C. This is achieved by having a gas such as nitrogen in the space above the mercury. When the mercury rises up the stem, this gas is compressed sufficiently to prevent the mercury boiling at its normal boiling-point.

To Construct a Graph for Interchanging Degrees Centigrade and Degrees Fahrenheit (fig. 100)[1]—On a sheet of squared paper draw two lines at right angles for axes of C. and F. as shown, and allow each scale to extend from the upper fixed point to −50°. Mark the fixed points A and B and join by a straight line. Use the graph to fill in the following tables:—

(*a*)

Degrees C.	10	20	30	40	50	60	70	80
Degrees F.								

(*b*)

Degrees F.	0	10	20	50	80	120	170
Degrees C.							

(*c*) From the graph find out at what temperatures the two scales read alike.

Maximum and Minimum Thermometers—It is often useful to be able to tell the maximum or minimum temperature reached during a certain period. This is specially important in greenhouses, where too low or too high a temperature may cause serious trouble to sensitive plants. It would be rather tedious to sit up all night reading a thermometer, and this is avoided by making use of maximum and minimum thermometers.

Minimum.—Rutherford's minimum thermometer (fig. 101) contains alcohol instead of mercury, and is hung in a horizontal position. In the stem is a small glass pin, which is dragged back by the meniscus as the temperature falls and is left at the lowest point reached. To re-set the thermometer it is gently tilted, when the pin falls to the meniscus.

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[1] *Note*—It is useful to have such a graph on the wall of the laboratory so that F. and C. thermometers can be used at will and their scales converted one into the other.

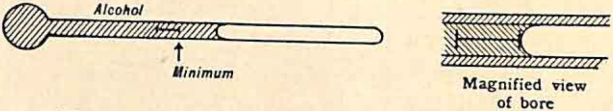

FIG. 101.—Rutherford's minimum thermometer

Maximum—Rutherford's maximum thermometer is similar, but contains mercury, which pushes the pin along as the temperature rises (fig. 102).

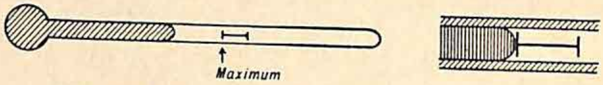

FIG. 102.—Rutherford's maximum thermometer

Six's Combined Maximum and Minimum Thermometer—This is shown in fig. 103, which you should study. To re-set

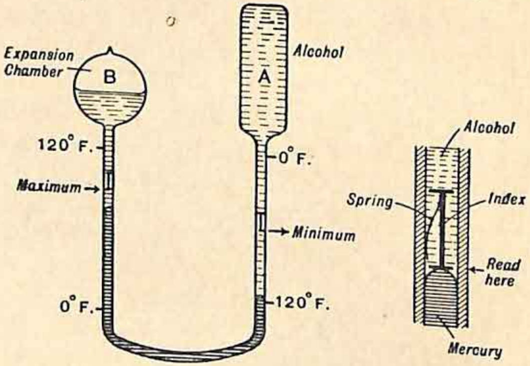

FIG. 103.

the steel pins a magnet is used. The alcohol in A is the expanding liquid; the mercury acts as an index (although it expands as well, but not by any means so much as the alcohol. *Why not?*). B is an expansion chamber. *What* *would happen when the temperature rose if there was no space above the liquid in* B *?*

The Clinical Thermometer—Clean the bulb of an ordinary thermometer. Place it under your tongue for a minute or two and then read your temperature. If the thermometer is marked in Centigrade, convert the reading into degrees Fahrenheit by means of your graph. A healthy body should be at 98·4° F. *What difficulties did you experience in trying to read your temperature in this way ?* To get over the difficulty we require a suitable maximum thermometer, and such a one is a *clinical thermometer* (fig. 104). Examine this and point out the differences you notice between it and the usual Centigrade or Fahrenheit thermometers. Do not pay too much attention to the time marked on the instrument. It often takes a so-called " half-minute " thermometer about two minutes to reach the temperature of the body.

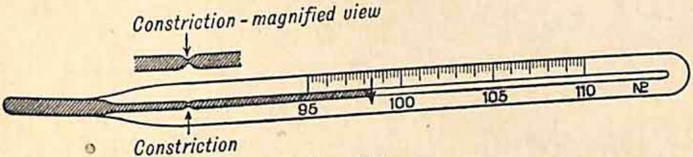

Fig. 104.

When the clinical thermometer is taken out of the mouth or from under the armpit (it is unsafe to place one in a baby's mouth) the mercury thread breaks at the constriction and so the temperature can be read. To re-set the thermometer the mercury is shaken down to two or three degrees below the normal.

It is interesting to know that the mercury rise for each degree F. represents only a ten-thousandth part of the volume of the bulb. The glass of the stem behaves like a cylindrical lens and magnifies the breadth of the stem.

At the National Physical Laboratory the testing of clinical thermometers is carried out on a large scale, over 300,000 being tested each year. The mark NP etched on a clinical thermometer means it is certified as accurate by the N.P.L. To graduate the thermometers they are placed in baths of well-stirred water kept at fixed temperatures by means of thermostats.

If a person's temperature is 100° F. or above he may have a chill ; if 101° or 102°, a fever ; 105° F. is dangerous to life. If the temperature persists above 100° F. the person should stay in bed and a doctor should be called.

Historical Notes on Thermometers—The first recorded attempts to measure temperature were made by Galileo (1564–1642), who used an inverted vessel of air with a water index to register the temperature of the atmosphere (fig. 105). This was found to be unreliable. *Can you suggest why?*

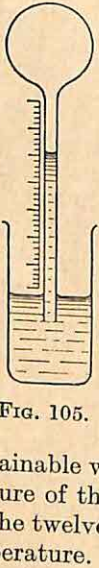

Fig. 105.

In 1612 Galileo made an alcohol thermometer, open at the top, the divisions marked on the stem being fractions of the volume of the bulb. Copies of both of these early thermometers may be seen at the Science Museum.

The necessity of fixed points was realised by Sir Isaac Newton in 1701. He suggested for these the freezing-point of water, calling it 0°, and the temperature of the human body, which he called 12°.

It was Fahrenheit who, in 1713, proposed for the lower fixed point the lowest temperature obtainable with ice and salt. This he called 0°, and the temperature of the human body he called 12°. He subdivided each of the twelve degrees into 8, making 96 in all for the body temperature. Later he found that the temperature of boiling water varies with pressure, but was always the same at the same pressure. Then, if a fixed pressure was specified, the boiling-point of water could be used as a fixed point. He then graduated his *thermometer* to show the freezing-point and boiling-point of water and the boiling-point under normal pressure, and these came out at 32° and 212° of his original scale. It was not until 1742 that Celsius, a Swede, adopted 0° and 100° for these temperatures. In his honour a Centigrade thermometer is sometimes called a Celsius thermometer, especially on the Continent.

The Changes which take place when Water is Frozen—Fill a test-tube 6 in. × $\frac{5}{8}$ in. with water. Insert a cork and wire it on. Leave it outside on a frosty night. On examining it next morning it is found to be broken and the water is turned into ice. One cannot command a frosty night at will, so an alternative experiment is to obtain a small bottle with a screw stopper,[1] fill it with water, and screw on the stopper. Cover it with a mixture of pounded ice and salt (fig. 106). This is called a "freezing mixture." After about twenty minutes take out the bottle and examine it. Write a full account of what you observe. *Is there any change of volume when water freezes? Which occupies the bigger volume, a pound of ice or a pound of water? Does ice float or sink in water?*

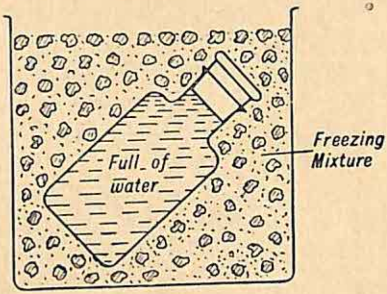

Fig. 106.

When do water pipes burst—during a frost or during a thaw? When is the burst discovered?

The fact that ice floats on water does not explain why ice always forms on the top of a pond. If the water at the bottom cooled to 0° C. we should expect some ice to get entangled in the weeds, and this would grow by accretion. Thus in time the bottom would be covered with ice, and the consequences to animal life would be disastrous: the fishes would starve to death in a prolonged frost. Something unusual must happen to water near to its freezing-point.

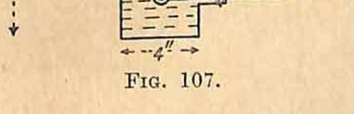

Fig. 107.

The Behaviour of Water as it Cools from about 10° to 0° C.—Hope's apparatus consists of a glass jar surrounded at its middle by a vessel, as shown in fig. 107. The glass vessel has side openings above and below, through which thermometers fit. Fill the glass vessel with water at a temperature not higher than 10° C., and pack the outer tube with a freezing mixture of pounded ice or snow and salt.[1] Set up the apparatus in a cool part of the room and read the thermometers every minute for about an hour. Plot the results on a graph (fig. 108). The reading of the lower thermometer falls first, but stops at about 4° C. The upper thermometer keeps at about 10° C. for some time and then falls rapidly to 0° C. Now the *denser* water will sink to the bottom, and evidently ***water is densest at about* 4° *C*.** Thus when the water at the top of a pond begins to freeze, that at the bottom is at 4° C.

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[1] These can be bought for a penny from a chemist.

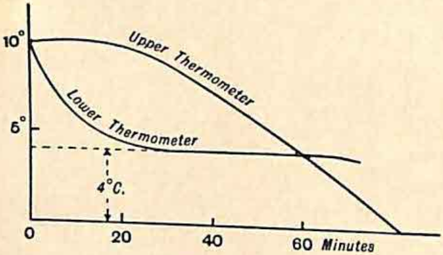

Fig. 108.

The Changes which occur when Tap-Water is Heated—Half fill a clean tin with tap-water. Support it on a tripod stand with a thermometer inserted and watch carefully as the can is heated with a *small* flame. Note any changes, and the temperature at which they occur. If any bubbles form, note the temperature and also any alteration in size as they rise. Note particularly the temperature at which "singing" begins and stops. Watch what happens to any bubbles when singing is going on. After the water has boiled turn out the Bunsen and listen as the water cools to find out if "singing" begins again. Lift the tin off the hot tripod and notice if the singing persists. Repeat the experiment in a glass beaker so that you can observe exactly what happens at the temperatures already noted. You may not get the singing in this case, but will notice what happens to the rising bubbles.

It will be interesting to consider the question:

"Why does a Kettle Sing?"—In the experiment on heating water you noticed at first bubbles rise, which got larger as they arose; these were bubbles of dissolved air. When the water was nearly boiling you noticed the bubbles, which started at the hot base of the beaker, got smaller, and collapsed before reaching the surface. These were bubbles of *steam*, and they collapsed as they reached cooler water above. Whenever a bubble starts at the bottom the surface of the water rises a little, and when a bubble collapses it falls a little. When these rises and falls succeed each other rapidly enough waves are set up in the air above. When these waves succeed each other rapidly enough a musical note is heard. This is the singing of the kettle, and it only takes place just before the water boils, for when the water is boiling it is at boiling-point all over and the bubbles no longer collapse. It will be interesting for you to try to find out the effect of removing and replacing the lid of the kettle.

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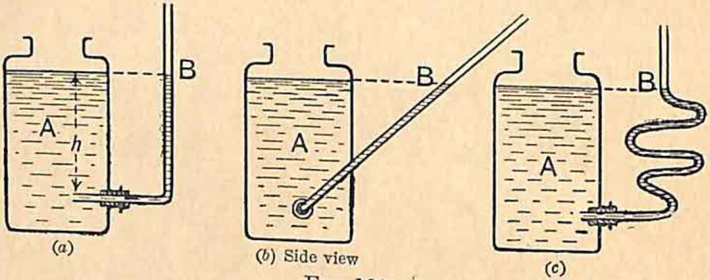
[1] Continue to add ice and salt throughout the experiment so as to maintain the source of cooling. This will ensure success.

CHAPTER XI

PRESSURE IN LIQUIDS

A IS a large glass vessel fitted with openings at the top and side. To the side opening is fitted a glass tube of about $\frac{3}{8}$-in. bore. Pour water into A and note the levels in A and B. Turn tube B as in fig. 109 (*b*). There is now more water in B than there was before, but the levels are still the same. Now fit a contorted tube into A and repeat the experiment. Try the effect of inclining tube B when your finger is over the open end. *Do the levels still remain the same?* Release your finger and note what now happens.



(*a*) (*b*) Side view (*c*)

FIG. 109.

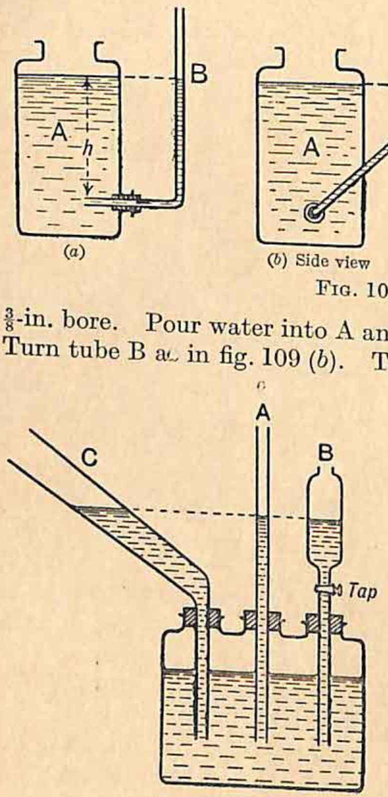
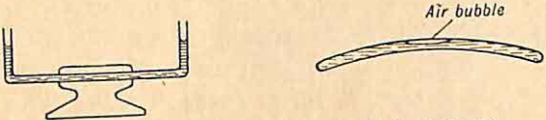


FIG. 110.

No matter what is the shape or inclination of the tube, the liquid remains at the same level in B *as in* A, *provided both are open to the air.*

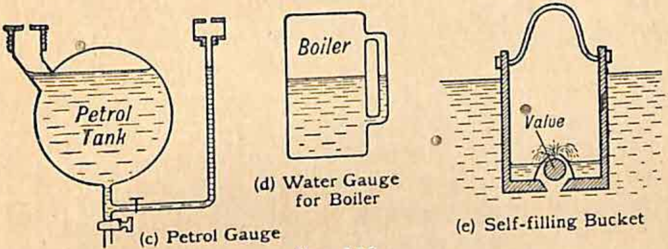
The apparatus illustrates the popular saying that "*A liquid tends to find its own level.*" This only means that if we connect tubes of the same liquid, all being exposed to the air at the surface, their surfaces will attain the same level. This is shown in fig. 110. Pour water into tube B until the levels are as shown. Note the horizontal level. Close tap B and suck at A. *What happens, and why?*

This principle is of great practical importance. Water levellers are still used by miners when prospecting for ore, and in the past they were used by surveyors on theodolites. Fig. 111 illustrates other familiar applications.



(a) Levelling by water tube

(b) Spirit Level



(c) Petrol Gauge

(d) Water Gauge for Boiler

(e) Self-filling Bucket

FIG. 111.

A Town's Water Supply depends on the fact that the surfaces of water in connected tubes tend to become level. In many small towns the water is pumped from deep wells and is then forced up through pipes into towers placed on the highest point of the town. Pipes connect the houses to the supply, and as the water-level in the tower is higher than the houses, whenever a tap is turned water rushes out. The lower the tap below the tower, the greater the force with which the water rushes out. *If only cold water is required this should be supplied directly from the main, a tank being unnecessary.* If a hot-water system is also installed a cold-water tank *must* be provided. It is usual for the cold-water tank to be installed under the roof of the house. This is a bad plan, for not only is this an awkward place to get at, but in wintry weather it is the coldest part of the house and so the water is most likely to freeze there. The best place for the cold-water tank is above the hot-water cistern, which is often placed in a cupboard for the convenience of airing clothes. The cold-water tank is kept full of water from the mains by means of valves. These open when the water-level in the tank falls, and close when the water rises to a certain level. The principle of the valve's action will be understood from fig. 112.

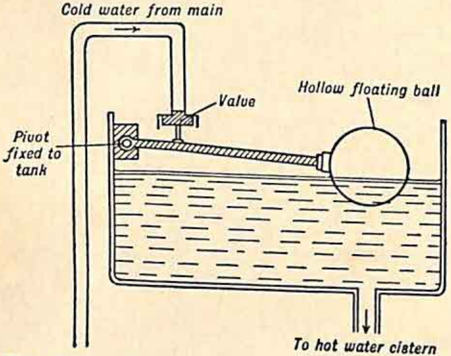


Fig. 112.—The valve controlling the supply of water to the cold tank

In the case of large towns water is stored in reservoirs in the mountains, often many miles from the town. It is brought to the neighbourhood of the town in large pipes and passes into artificial reservoirs, the floors of which are gigantic filters, many acres in extent. The bottom is concrete, then comes a thick layer of gravel, and finally sand. The water oozes through the sand, and is then collected through screened pipes which pass through the concrete into the gravel. It is then pumped clean and pure into the town mains. There are usually several of these reservoirs at each filtering station, so that water can be drained off each at intervals. This enables one filter-bed to be cleaned without cutting off the water supply from the town.

Artesian Wells—If the geological formation in a certain neighbourhood is as shown in fig. 113, it is possible for great stores of water to collect in the lower porous stratum. If a well is bored through the non-porous layer above, the water will rush up in an attempt to "find its own level." The well is called an "artesian" well, after the province of Artois in France, where such wells have been known since A.D. 1100.

They are a feature of the dry interior of Australia, and many old wells in London are artesian, with depths of 300 feet and over.

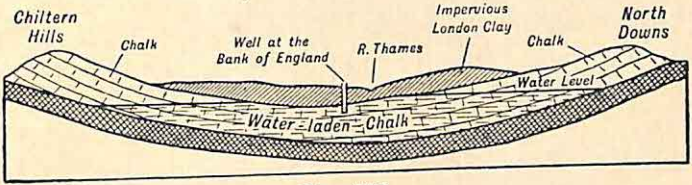


FIG. 113.

An Experiment on Fluid Pressure—A, B, C, and D (fig. 114) are four glass vessels,[1] the lower ends of which are ground flat; against each presses a thick card held by a string.

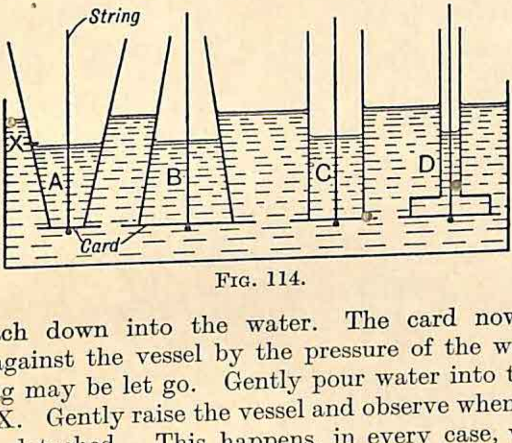


FIG. 114.

Push each down into the water. The card now presses tightly against the vessel by the pressure of the water, and the string may be let go. Gently pour water into the vessel to level X. Gently raise the vessel and observe when the card becomes detached. This happens, in every case, when the water-level is the same inside as outside. It is evident that the *weights* of water in the vessels differ greatly in the experiments.

By the principle of Archimedes we know there is an up-thrust on the card. The card comes away when the down-thrust of the water in the vessel is equal to the upthrust of the water in the tank. As the vessels are of different shapes, we conclude that the downthrust of a liquid on the base of a vessel is independent of the shape, but depends on the depth.

[1] Various types of lampshade will do.

The thrust on unit area is called the pressure.

Thrust = pressure × area.

Thus if the pressure on a surface is 10 lb. weight per sq. in., the thrust on 4 sq. in. will be 10 × 4 = 40 lb. weight.

How does the Pressure in a Liquid depend on the Depth ?— Connect a thistle funnel to a **U**-tube containing water or oil (fig. 115). Gently lower the thistle funnel into some water in a tall jar. Measure the depth *d* of the surface of water in the thistle funnel below that of the water in the jar. Measure also the "head" *h* of the liquid in the **U**-tube. Tabulate your results. Draw a graph showing *h* vertically and *d* horizontally.

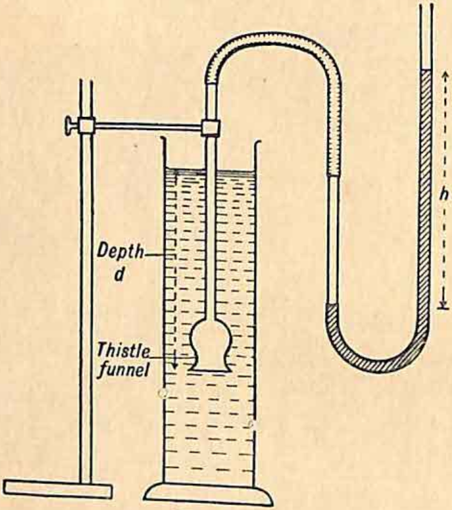


FIG. 115.

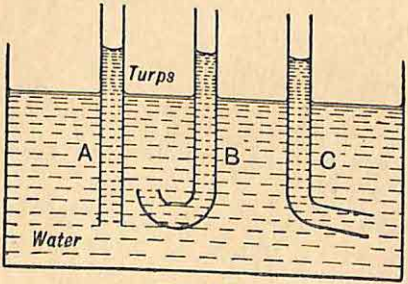


FIG. 116.

Obtain three glass tubes of the shapes shown in fig. 116. Insert each in turn into some turpentine and withdraw it, keeping one finger tight over the end. Lower, and fix each when the lower ends are at the same depth in a tank of water. On releasing the finger some of the turpentine runs out until the levels are the same. *Why is the turpentine level higher than that of the water?* In A the water is pressing upwards, in B downwards, and in C sideways. *What do you conclude about the pressure in different directions at a certain depth?*

So far you have learnt that the pressure exerted on a liquid at a certain depth (*a*) is proportionate to the depth, (*b*) acts equally in all directions.

Now repeat the thistle-funnel experiment, using (*a*) water and (*b*) mercury in the U-tube. Plot graphs showing the variation of "head" *h* with depth *d*. If you measure the two "heads" at a particular depth *d*, you will find the water "head" is about 13·6 times that of the mercury "head." You already know that 13·6 is the relative density of mercury. A "head" of 1 cm. of mercury is therefore equivalent to a "head" of 13·6 cm. of water.

The pressure in a liquid is evidently proportional to the density of the liquid.

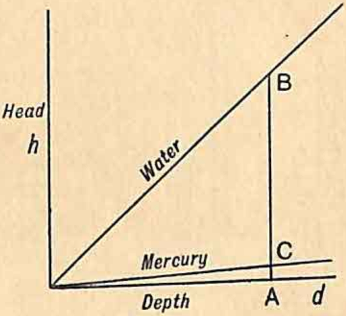


Fig. 117.

To summarise:

Pressure varies as depth.
Pressure varies as density.

To measure pressure, we multiply head by density, or

Pressure = head × density.

The pressure at a depth 20 cm. in water will be 20 grm. weight per sq. cm. At the same depth in mercury it will be 20 × 13·6 grm. weight per sq. cm.

At a depth of 20 cm. in methylated spirits (density 0·8 grm. per c.c.) it will be 20 × 0·8 grm. weight per sq. cm.

"The Hydrostatic Paradox"—Attach a long, bent glass tube securely to the opening of a football bladder. Place on the bladder a tin supporting a large weight. Pour water into the glass tube. The bladder is gradually distended and the weight is raised. Provided the glass tube is long enough and securely fastened to the bladder, a small boy sitting on the tin may be raised by pouring water into the tube.

The ancients called this experiment the hydrostatic paradox—it appeared so wonderful that a large weight could be lifted by this simple means. *What is the secret?*

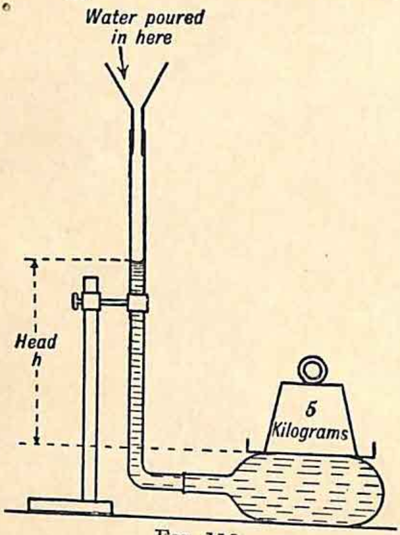


FIG. 118.

Stop pouring water into the tube. Measure the head of the water in the tube. Suppose this is 25 cm. The *pressure* on the tin is 25 grm. weight per sq. cm. If the area of the tin in contact with the bladder is 200 sq. cm., the *thrust* will be

200 × 25 = 5000 grm. wt.
= 5 Kilograms wt.

This experiment shows the principle of the hydraulic transmission of pressure.

The Hydraulic Transmission of Pressure, known as Pascal's Principle—A piston A, of area 10 sq. cm., supporting a 1-lb. weight, will hold up another piston B, of area 1000 sq. cm., which supports a 100-lb. weight (fig. 119). The *pressure* is the same on each piston, but the thrusts are different.

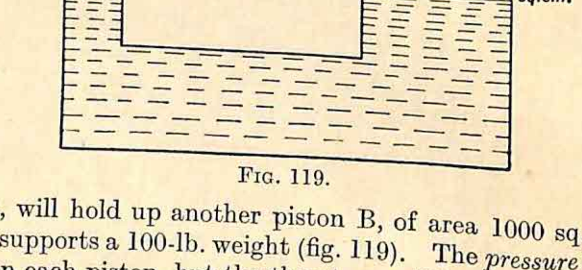


FIG. 119.

A common device in canals is the lift-lock, which is used where there is a great difference of level. The principle is shown in fig. 120. The lock consists of two great hydraulic elevators which support the vessels to be raised or lowered, in tanks X and Y, supported on pistons A and B. The vessel is towed into tank Y, which is, say, at the lower level, and the gates are closed. The valve is then opened and the additional weight of water in X causes it to descend, forcing the water from press C into D and raising the tank Y.

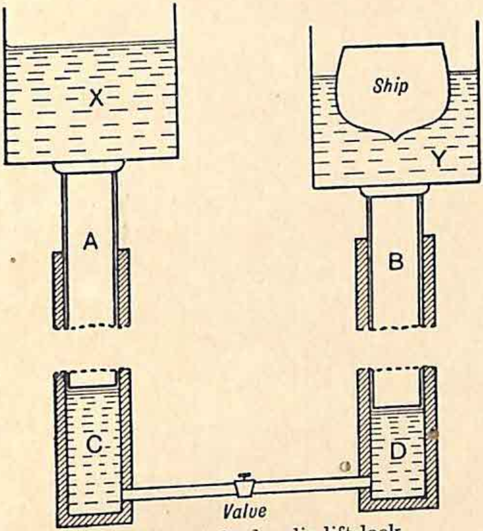


Fig. 120.—A hydraulic lift-lock

Comparing Densities of Liquids by means of Pressure—Fit up the apparatus shown (fig. 121). It is known as "Hare's apparatus." One beaker contains water, the other brine or other liquid whose density is required. (When using acids take care not to get any in your mouth.) Open the clip and draw the liquids into the tubes. Close the clip, measure the "heads" h_1 and h_2.

The pressures on the surfaces of the liquids in the beakers are equal; the pressures on the surfaces in the tubes are also equal.

Let d_1 and d_2 be the densities,

$$h_1 d_1 = h_2 d_2 = \text{difference of pressure on the liquid surfaces.}$$

$$\therefore \frac{d_2}{d_1} = \frac{h_1}{h_2},$$

and as $d_1 = 1$ grm. per c.c. for water,

$$\text{density of } \textit{liquid} = \frac{\text{head of } \textit{water}}{\text{head of } \textit{liquid}}.$$

Tabulate your results; obtain several for each of different liquids and work out the average result in each case.

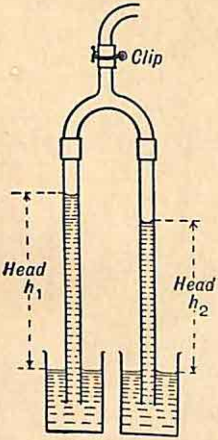


FIG. 121
Hare's apparatus

Pressure and Thrust—We have learnt that by pressure is meant the force or thrust acting on unit area. It will be well to consider this idea further.

Suppose we have a cube of metal 1 cm. side weighing 9 grm. The *force* or thrust on the base is 9 grm. weight, and the *pressure* is 9 grm. weight per sq. cm. If we place a similar block alongside the first the *total thrust* is now 18 grm. weight, but the pressure is still 9 grm. per sq. cm. If the second block is placed upon the first the *total thrust* is still 18 grm. weight, but the pressure is 18 grm. weight per sq. cm.

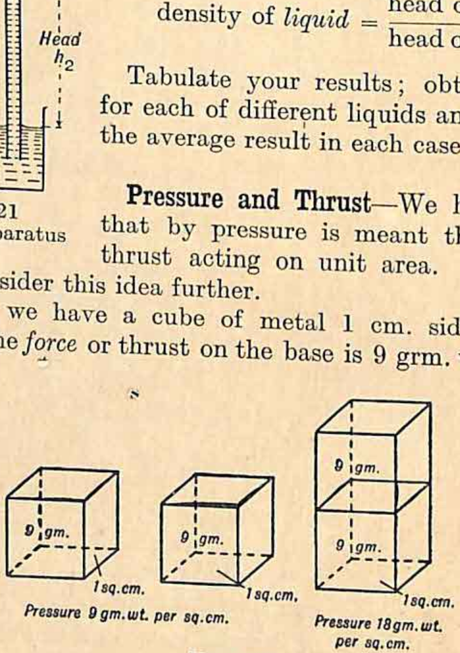


FIG. 122.

Exercise—Calculate the pressure and the thrust produced by a cube of iron 3 cm. side, density 7 grm. per c.c.

Fill in the spaces in the following table. They refer to rectangular blocks of metal.

Material	Density	Dimensions of base	Height	Pressure on base	Thrust on base
	grm. per c.c. 9	cm. 4 × 3	cm. 2		
		3 × 2	4		
	2·7	5 × 4	6		
		4 × 6	5		
	lb. per cu. ft. 156	ft. 2 × 1	ft. 3		
		3 × 2	1		

CHAPTER XII

THE PRESSURE OF THE ATMOSPHERE

OBTAIN a large tin can which has soldered seams. Pour a little water in and boil it. When steam is issuing freely from the mouth remove the can from the flame and at once insert a tight-fitting bung. Leave the can on a bench and watch it. Listen carefully, and note everything that you observe.

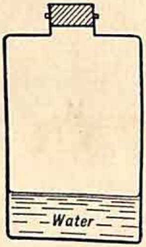


FIG. 123.

Was there air inside the can when the bung was inserted ?

What was there above the water ?

What happened to this as the can cooled ?

Explain what finally happened to the can.

Boil a little water in a test-tube. When the water is boiling remove the test-tube from the flame and insert a rubber bung. Put the test-tube mouth downwards in cold water and try to remove the bung. (*Caution*—Hold the tube in a duster.) Explain what happens.

These experiments show that the air is capable of exerting great pressure.

It is strange to think that up to comparatively recent times it was not suspected that the air exerted pressure, and this in spite of the fact that pumps had been used from the earliest times to raise water from wells.

Place the nozzle of an ordinary syringe in water and pull up the piston. Water rises into the syringe. The ancients thought that when the piston was pulled up it tended to make a vacuum, and they said that the water rose because Nature would not tolerate a vacuum. They thought water was "sucked up" into the syringe, just as if the vacuum *pulled* it up. We shall consider the true explanation when we have performed the following experiments.

Simple Experiments on Air Pressure

(*a*) Fill a tumbler with water. Place a piece of glazed paper over the top and press tightly round the edges of the tumbler. Invert the tumbler. The paper remains in position and the air holds up a tumblerful of water.

(*b*) A circular disc of thin leather through the centre of which passes a piece of string, which is secured by a knot on the underside, acts as a boy's "sucker" (fig. 124). If this is moistened and pressed out on the surface of a piece of wood, or on a stone, the object can be lifted.

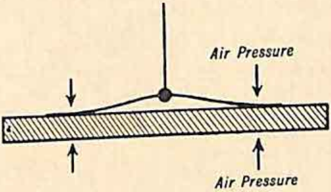


Fig. 124.—The "sucker"

(*c*) The principle of the boy's "sucker" is now used in the manufacture of portable coat-hooks. These consist of a rubber disc through the centre of which passes a metal hook. The disc is moistened and pressed firmly against a door or wall, thus providing a convenient hook on which to hang a coat for a short time (fig. 125).

(*d*) Stretch a piece of rubber tightly over the mouth of a small glass jam-jar and tie securely in position. Place the jar under the bell-jar of an air-pump. Pump as much air as possible out of the bell-jar. Note what happens to the rubber disc, and explain. Try to lift the bell-jar from off the brass disc. Explain why it is difficult.

(*e*) Tie a piece of thin rubber over the mouth of a thistle funnel. Suck the air out from the end of the stem. Again say what happens, and explain.

(*f*) Now try to explain why you can suck water or other liquid into a pipette. Explain by means of a diagram.

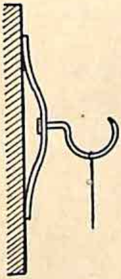


Fig. 125.

(*g*) Fit a long glass tube with a cork through which a glass tube passes, and support it with the open end in water (fig. 126). Attach the tube to an air-pump or to a Bunsen water-pump by thick rubber tubing. Turn on the water. As the air is driven out of the tube the water rises. *Why does it rise?* This suggests the reason for the water entering the syringe referred to in the introduction.

To find out to what Height the Air Pressure can force Water—Evidently to do the experiment with water we should require a very long tube. If we could use a liquid twice as dense as water we should only require half that length of tube. Let us use mercury, which is 13·6 times as dense as water.

Obtain a thick-walled glass tube, at least a yard long, open at both ends, and support it vertically with its lower end in a jar of mercury, standing on a mercury tray (fig. 127). Connect the upper end by thick rubber tubing to a good Bunsen water-pump. This should be fixed on to a tap which has a good pressure of water. Turn on the tap as far as it will go and watch what happens to the mercury. When the mercury has stopped rising, measure the "head" in centimetres and inches. Calculate the "head" of water which would be supported by air pressure.

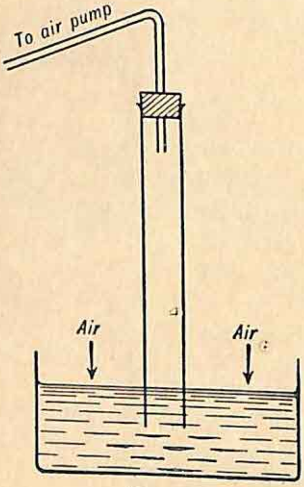


Fig. 126.

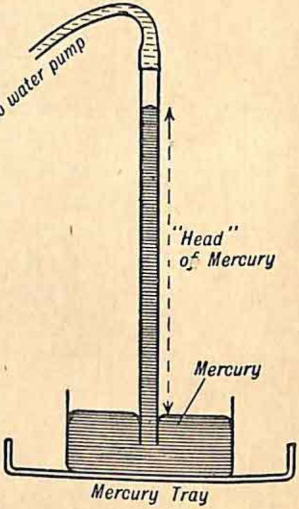


Fig. 127.

Results :

Head of mercury = ...
Relative density of mercury = 13·6.

∴ head of water which air pressure will support
= .... × ....
= in.
= ft.

It should be mentioned that the space above the mercury is not *quite* a perfect vacuum, but contains a little water vapour. If there was a perfect vacuum above the mercury the head would be a little higher. Let us now modify the experiment in such a way as to have no water vapour above the mercury.

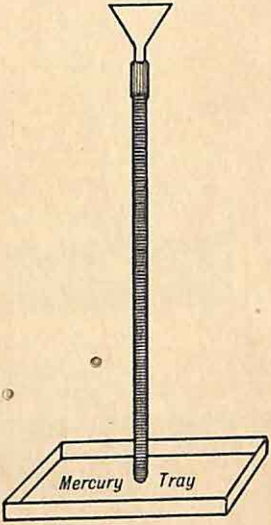


Fig. 128.

To Measure the Pressure of the Atmosphere—Obtain a *clean* and *dry* thick-walled glass tube about 33 in. or a yard long, closed at one end. Attach a clean, dry piece of rubber tubing to the open end and connect it to a clean, dry funnel. Pour in mercury which has been filtered so that it is also *clean and dry. This should be done over a mercury tray* (fig. 128). When the tube is full of mercury remove the funnel. Tap a little mercury out of the tube, leaving a fairly large air-bubble. Close the end with a finger and carefully invert the tube, so allowing the air-bubble to run to the closed end and back. This will remove any small air-bubbles sticking to the sides. Fill up the tube with mercury, close the end as before and invert the tube, placing the mouth under the surface of some mercury in a bowl. Remove your finger. Support the tube by a stand and clamp. *Did any air enter the tube?* If it did, the experiment must be repeated. *Is the tube still full of mercury? What is in the space above the mercury?*

Arrange a horizontal ruler so as to be level with the top of the mercury in the tube (fig. 129). Tilt the tube slowly and watch what happens. *Does the level alter?*

Show in a sketch the position of the mercury surface with the tube at various angles. Measure the "head" of mercury in inches and in centimetres. *Is it greater or less than in the last experiment?* Calculate the head of water which the air pressure will support. Express it in feet.

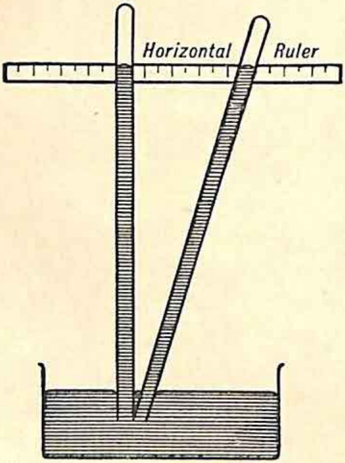


Fig. 129.

Arrange the tube vertically. You have set up a *barometer*—an instrument for measuring the air pressure.

Now weigh a large evaporating basin. Then carefully raise the tube until the lower end is only just under the surface of the mercury in the dish. Close the open end with a finger, and pour the mercury from the tube into the weighed dish, and find its weight.

Find the area of the cross-section of the bore of the tube. Now calculate the pressure of the mercury in grams per square centimetre. It is equal to the pressure of the atmosphere.

Results:

Weight of evaporating dish = ... grm.

" " " and mercury = ... "

∴ weight of mercury in tube (W) = ... "

Area of bore of tube (A) = ... sq. cm.

W grms. of mercury press on A sq. cm.

∴ pressure of mercury $= \frac{W}{A}$

= . . . . grm. per sq. cm.

∴ **pressure of the atmosphere** = ... grm. per sq. cm.

Convert this into lb. per sq. in., given that

1 sq. in. = 6·45 sq. cm.
1 lb. = 454 grm.

The experiment you have done was first performed by an Italian, Torricelli, in 1642, and created quite a sensation. The space above the mercury was a vacuum, and the experiment proved the old saying that "Nature hates a vacuum" to be untrue. Soon after Torricelli did his experiment, Pascal repeated it in France, and to make quite sure that it was the air which forced the mercury up the tube, he arranged for a barometer to be taken up a mountain, with the result that as the height increased the head of mercury gradually became less. For a height of about 1000 ft. the "head" decreased by about 1 in. This experiment settled the question beyond reasonable doubt, for the higher one goes the less is the weight of air pressing down.

BAROMETERS

Types of Barometers in Common Use

The Siphon Barometer—This is sufficiently described by fig. 130. The idea is probably due to Boyle, who, incidentally, invented the term "barometer." When a reading is to be taken, the glass case is tapped in order to overcome friction in the pulley and between the float and the tube. Barometers of this type are usually marked "Much rain," "Rain," "Change," "Set fair," *but you should take no notice of these markings.* As you will learn later, the important thing is to note whether the mercury rises or falls. Siphon

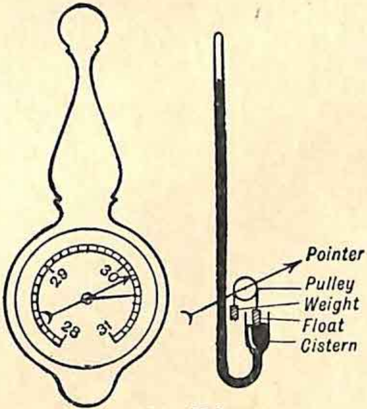


Fig. 130.

barometers are useful for rough readings but not where great accuracy is required.

Accurate barometers for use in the numerous observing stations connected with the Meteorological Office must possess some means of setting the zero of the scale before taking readings, and also some device for reading the scale with great accuracy. This is achieved in

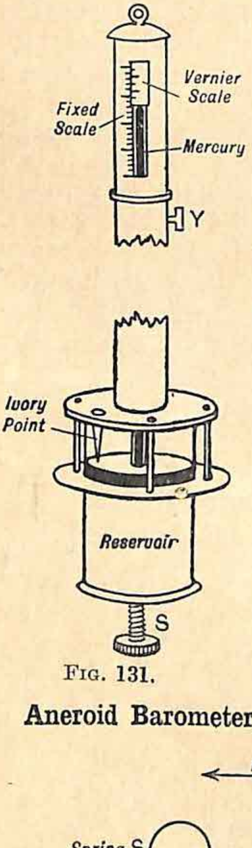


FIG. 131.

Fortin's Barometer—The mercury in the reservoir is contained in a chamois-leather bag against which bears a screw S. To set the zero, S is turned until the mercury surface just touches an ivory point which is fixed at the zero of the scale. The screw Y is connected to a vernier scale and is turned until this is level with the top of the mercury meniscus. By means of the vernier the reading is obtained with an accuracy of 0·01 in., or 0·01 cm. Corrections have to be made for the effect of temperature on the scale and on the density of the mercury; also for latitude and altitude, as all readings are adjusted to sea-level and to latitude 45°. For details of these corrections a more advanced book must be consulted.

Aneroid Barometers—The word "aneroid" means "with-

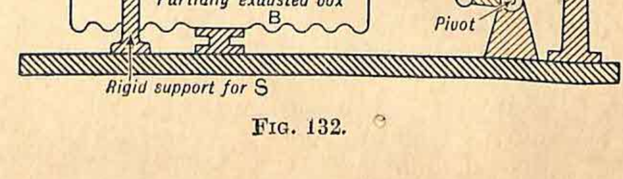


FIG. 132.

out liquid." An aneroid barometer consists of a thin metal box, B, from which most of the air has been extracted. When the air pressure increases the sides are pressed closer

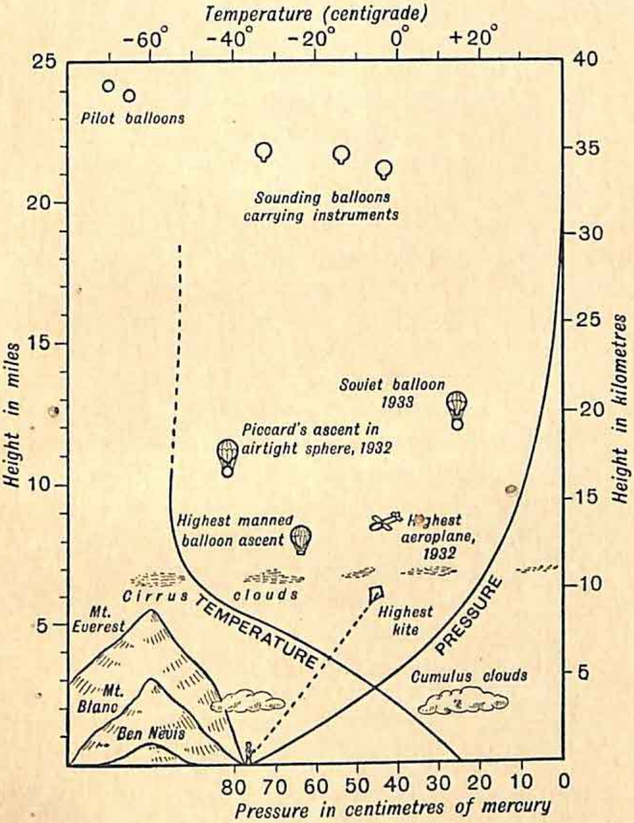


FIG. 133.—The average pressure and temperature of the upper air in summer in latitude 45°

together, and when the pressure decreases the spring S forces the sides further apart. By means of the system of levers shown these changes are made to move the pointer, which moves over a dial, omitted in the sketch.

Aneroid barometers may be made small enough to go in a vest pocket, and these are marked with scales showing pressure and also altitude. By carrying one of these on a climbing expedition you may find the height reached. The *Altimeter* carried in an aeroplane is just such an instrument.

It is interesting to learn that in 1790 the Frenchman Conté, Director of the School of Aerostatics at Meudon, invented a primitive form of aneroid and used it to measure the altitude of balloons during Napoleon's Egyptian campaign. The instrument was first patented as a barometer in 1845 by Lucien Vidie, but Conté was undoubtedly the inventor.

Fig. 133 shows the average pressure and temperature of the air in summer to a height of 25 miles. On 27th May 1931, Piccard and Kipfer of Brussels ascended to a height of nearly 10 miles in an airtight aluminium sphere, 2 metres in diameter, attached to a balloon of capacity 500,000 cu. ft. The oxygen in the air inside the sphere was renewed from cylinders of the gas. The temperature outside the sphere was −55° C. From the diagram you may find the pressure outside the sphere at this height.[1]

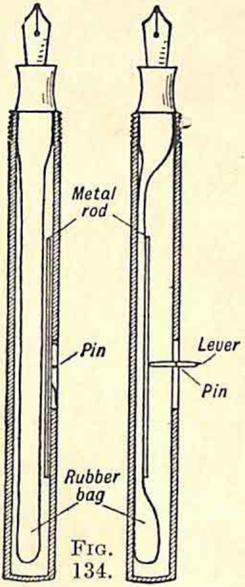


FIG. 134.

How the Barometer helps to Foretell the Weather—You should take readings of the barometer at set times each day for some weeks. Show the results as a graph on a weather chart. Note the kind of weather each day. You will discover that if the barometer is rising slowly fine weather follows, whilst if it falls slowly wet weather follows. Rapid changes in the height of the barometer herald the approach of gales.

Some Appliances depending on Air Pressure

The Self-filling Fountain Pen—This contains a long rubber bag against which rests a metal rod. A lever is attached to the centre of this rod and works on a pin fixed to the barrel. On pulling out the lever the metal rod presses on the rubber bag, squeezing out some air. Pressing back the lever releases the bag, which resumes its former shape owing to its elasticity. This decreases the pressure inside, and if the nib is in the ink-bottle the atmospheric pressure forces some ink into the bag.

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[1] On 1st October 1933 a Soviet balloon with gondola attached reached a height of 62,320 ft., which is 9169 ft. higher than Piccard attained. Attempts to attain still greater heights are still being made.

The Lift-Pump—This type of pump is known to have been in use for thousands of years. A metal rod is connected to a piston through which passes a hole fitted with a valve on the top. The piston is usually cased with soft leather; so that it fits tightly in the metal barrel. At the bottom of this is a valve resting on the pipe which dips into the water in the well. The piston-rod is moved by means of a lever as shown.

Imagine that the piston is near the bottom of the barrel (fig. 135).

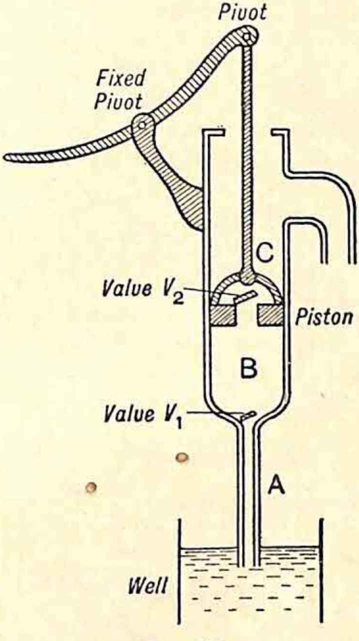


FIG. 135.

(a) *On the first upstroke of the piston* the pressure in B decreases. The outside air pressure acting through the spout closes valve V_2. The air also presses on the water in the well and drives some of it into B through valve V_1.

(b) *On the first downstroke of the piston* the pressure in B is increased, closes valve V_1 and opens valve V_2, driving some of the water into space C above the piston.

(c) *On the next upstroke of the piston* the pressure in B again decreases; and valve V_2 closes. More water from the well is driven into space B by air pressure. Also the water above the piston is *lifted* and some runs out of the spout. On continuing to work the pump stages (*b*) and (*c*) continue to succeed each other. (Note that water comes out of the spout only during the upstroke of the piston.)

The Force-Pump—The construction of this pump is easily followed from fig. 136. Its mode of action is as follows:—

(a) *On the first upstroke of the piston* the pressure in B decreases, valve V_2 is closed by the greater air pressure outside, which also drives water through valve V_1 into space B.

(b) *On the first downstroke of the piston* the pressure in B is increased, valve V_1 closes but V_2 opens, and water is *forced* into C. When C is full the water is *forced* out at S.

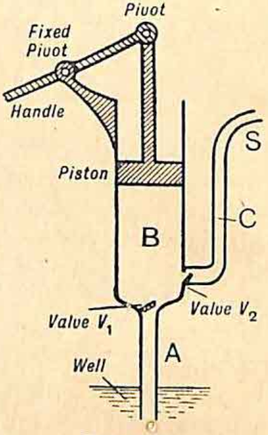


FIG. 136.

When a lift-pump is allowed to stand idle the leather of the piston dries up and contracts. To get the pump to work, water has to be poured in at the top first. This wets the leather, causing it to swell.

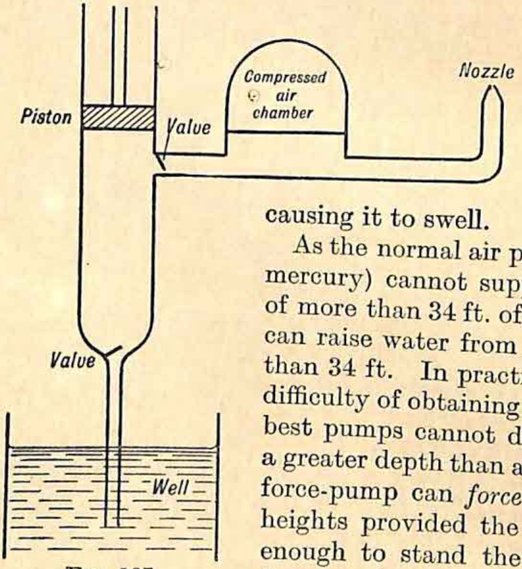


FIG. 137.

As the normal air pressure (30 in. of mercury) cannot support a "head" of more than 34 ft. of water, no pump can raise water from a greater depth than 34 ft. In practice, owing to the difficulty of obtaining tight joints, the best pumps cannot draw water from a greater depth than about 30 ft. The force-pump can *force* water to great heights provided the pump is strong enough to stand the great pressure. Some modern fire-engine pumps may force water to a height of hundreds of feet. In a modern force-pump an air chamber is provided in which the air gets compressed, and its pressure keeps the water flowing from the nozzle whilst the pump-piston is rising. Fig. 137 shows in diagram form the principle of the air chamber.

To Determine the Weight of a Litre of Air

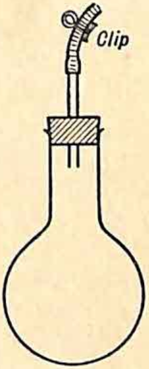


FIG. 138.

Demonstration — Obtain a round-bottomed flask about 4 in. in diameter. Fit it with a rubber bung through which passes a short glass tube. To the end of this fix a piece of pressure tubing about 3 in. long, closed by a screw clip.

Weigh on a sensitive balance the flask, bung, etc., full of air. Next attach the apparatus to a good vacuum pump and exhaust for some time. Close the screw clip whilst the pump is still working, and then reweigh the flask. Place the flask neck downwards in water which has been boiled, and open the clip. Water rushes in to take the place of the air which has been removed. Find the volume of this water by means of a measuring jar. Do this very carefully.

Results :

Weight of flask, etc., full of air = grm.
Weight of flask, etc., after pumping air out = ,,
∴ weight of air pumped out = ,,
Volume of water rushing into flask = c.c.
∴ weight of c.c. of air = grm.
∴ weight of 1000 c.c. of air = ,,

Assuming that you pump all the air out of the flask, *will the pressure of the air in the room affect your results in this experiment ?*

The weight of a litre of any gas at normal or standard pressure (30 in., or 760 mm. of mercury) is known as its density.

If a good vacuum pump is not available, proceed as follows : Pour a little water into the flask and boil it. When steam has been issuing freely for a few minutes remove the source of heat and fasten the clip. Now weigh the flask. Open the clip and cool the flask. *Why does the rubber tube collapse ?* When cool, replace the clip and weigh again. Measure the volume of water in the flask. Then fill flask with water and find the total volume. Hence find the volume of the air which entered and was weighed. Find the weight of one litre.

The following table gives the densities of common gases :—

Densities of Common Gases

(at normal pressure and 0° C.)

Hydrogen	0·09 grm. per litre
Oxygen	1·44 ,, ,,
Nitrogen	1·26 ,, ,,
Carbon dioxide	1·98 ,, ,,
Air	1·29 (variable).

CHAPTER XIII

THE CHEMISTRY OF AIR

The Composition of Atmospheric Air and Respired Air—You have already learnt that the atmosphere is a gaseous envelope covering the surface of the earth. You have learnt also that air has weight—it is a material substance—and that changes in air pressure are accompanied by changes in weather.

Have you ever thought of the effect of air on substances that are burning ? Why, for instance, do you sometimes hold a sheet of metal or wood (or even a newspaper) in front of a dull fire or one which has just been lit ? Why do you draw out the metal plate which you often find below the grate in the ordinary house fire ? Why is it wise to roll yourself up in a thick rug if you have the misfortune to get on fire ? Evidently the air has something to do with burning. You realised this when you did experiments with the Bunsen burner. You should now try to answer the question, **Is the whole of the air concerned with burning ?**

Experiment 1

Stand a small porcelain dish on the top of a "beehive" shelf in a trough or large bowl. Cover the dish with a bell-jar, first removing the stopper. Now insert the stopper and arrange the glass rod, which carries a short length of copper wire, so that the end A very nearly touches the bottom of the dish. Remove the stopper and then the bell-jar. Put a small piece of phosphorus (about half the size of a pea) in the dish and replace the bell-jar. Measure the height of the water by means of a ruler (fig. 139). Warm the end A of the copper wire. Replace the stopper, pressing it in firmly. The heated wire ignites the phosphorus and the jar is soon filled with white fumes. After a few minutes these dissolve in the water, and the water rises inside the bell-jar. Pour water into the trough until it stands at the new level. *Why is this* *necessary?* Now measure the height of the water. Remembering what the level was before the phosphorus burnt, find how far the water has actually risen. *What fraction is this of the whole height of the bell-jar?* Remove the stopper from the bell-jar and insert a lighted taper. Now insert a lighted taper into another bell-jar containing air. *What happens in each case?*

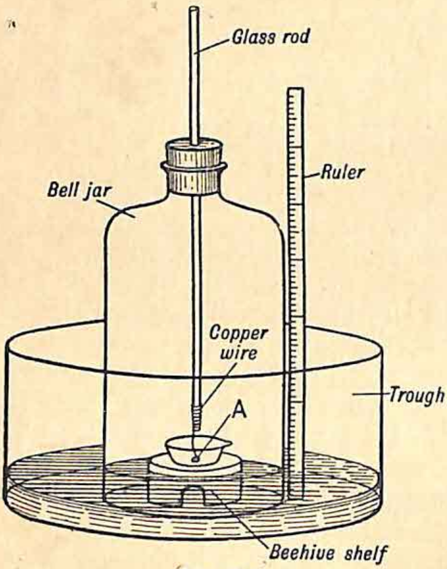


FIG. 139.

Experiment 2

Moisten with water the inside of a piece of glass tubing which is about $\frac{3}{4}$ in. wide and 2 ft. long and is closed at one end. Sprinkle some iron filings inside the tube, and by rotating the tube arrange that these filings cover practically the whole of the surface of the glass. Support the glass tube so that the open end is below the surface of water contained in a beaker (see fig. 140). Measure the length of the column of air inside the tube; leave it for several days. Fill up the beaker to the new level (this can be indicated by pasting a strip of paper on the outside of the beaker and marking the original level with a line on the paper); measure the height

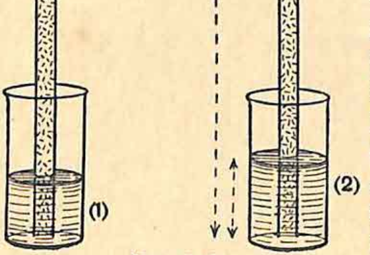


FIG. 140.

the water has risen inside the tube, and find what fraction this is of the original column of air. Close the open end of the tube by means of the thumb and take the tube out of the beaker, invert it, and insert a lighted match. *What happens?*

Experiment 3

A piece of phosphorus may be supported by means of a fairly stout copper wire inside a glass tube similar to the one used in the last experiment (fig. 141). This apparatus should be allowed to stand in the laboratory for several days, water in the beaker should be adjusted to the level inside the tube, and the same measurements taken as in the previous experiment.

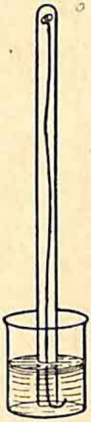


FIG. 141.

All the above experiments go to show that air is composed of two main portions, one that will support burning or rusting, and one that will not. The portion that will support burning is approximately one-fifth of the whole atmosphere, and was named by Lavoisier *Oxygen*. The inactive part which will not support burning is about four-fifths of the atmosphere, and is called *Nitrogen*.

Lavoisier's Experiment on the Composition of Air

For many years scientists were not at all clear as to what happened when substances burned in air. Lavoisier, a French scientist, performed a very important experiment, which can be imitated in the laboratory if you can fit up the apparatus and leave it for several weeks.

A flask with a wide neck is fitted with a rubber bung through which passes a wide delivery tube. The apparatus is fitted up as in fig. 142, the stopper at first being removed from the bell-jar so that the water may be at the same level in the trough and in the bell-jar. The mercury is heated with a moderate Bunsen flame. At first the water in the bell-jar goes down. *Can you suggest a reason for this?* The heating should continue for two or three weeks, and then the apparatus should be allowed to cool. The water in the trough is brought to the level of that inside the jar, and it is found that one-fifth of the air from the bell-jar has been removed, and that a scum —in places slightly reddish—has formed on the surface of the mercury. The gas left in the bell-jar will not support burning; it is in fact nitrogen. Lavoisier collected all the red scum from the surface of the mercury and heated it more strongly. He obtained just as much gas as the air had originally lost. This gas, which he called oxygen, allowed things to burn in it very brightly—in fact a glowing chip of wood inserted into the gas at once burst into flame.

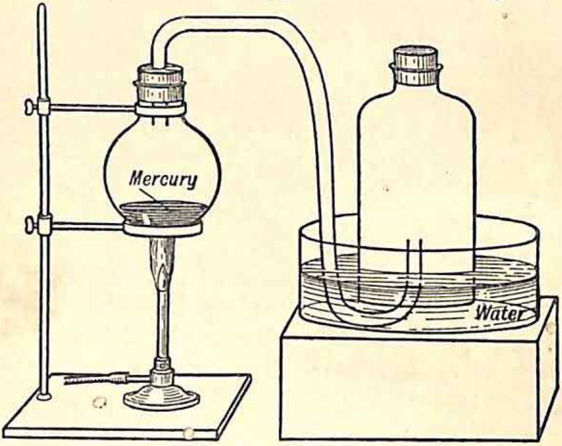
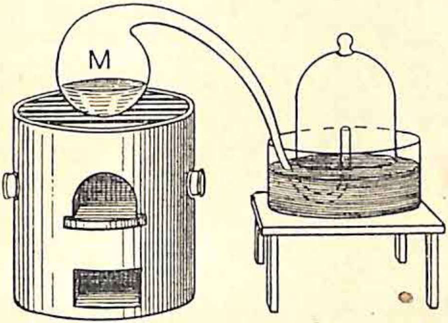


FIG. 142.

Priestley, an English scientist, had accidentally discovered this gas in 1774 when heating some red calx of mercury which had been given to him, but he had not understood that the gas was present in the atmosphere. Lavoisier's experiment is so important and so interesting that you should now read his own words:

"I took a retort of about 36 cubical inches capacity, having a long neck of six or seven lines (1 line = $\frac{1}{12}$ in.) internal diameter, and having bent the neck to allow its being placed in a furnace, in such a manner that the extremity of its neck might be inserted under a bell-glass placed in a trough of quicksilver; I introduced four ounces of pure mercury into the retort, and, by means of a syphon, exhausted the air in the receiver so as to make the quicksilver in the bell-jar rise above that in the trough, marking the height by pasting on a slip of paper. Having accurately noted the height of the thermometer and barometer, I lighted a fire in the furnace, which I kept up almost continually during twelve days, so as to keep the quicksilver always very near its boiling-point. Nothing remarkable took place during the first day; the mercury, though not boiling, was continually evaporating, and covered the interior surface of the vessel with small drops, which gradually augmenting to a sufficient size, fell back into the mass at the bottom of the vessel. On the second day, small red particles began to appear on the surface of the mercury; these, during the four or five following days, gradually increased in size and number, after which they ceased to increase in either respect. At the end of twelve days, seeing that the calcination of the mercury did not at all increase, I extinguished the fire, and allowed the vessel to cool. The bulk of the air in the body and neck of the retort, and in the bell-glass, reduced to a medium of 28 inches in the barometer and 54·5° of the thermometer, at the commencement of the experiment was about 50 cubical inches. At the end of the experiment the remaining air, reduced to the same medium pressure and temperature, was only between 42 and 43 cubical inches, consequently it had lost about $\frac{1}{6}$ of its bulk. Afterwards, having collected all the red particles formed during the experiment, from the running mercury in which they floated, I found these to amount to 45 grains.



Lavoisier's apparatus

"I was obliged to repeat this experiment several times, as it is difficult, in one experiment, both to preserve the whole air upon which we operate, and to collect the whole of the red particles, or calx of mercury, which is formed during the calcination. It will often happen in the sequel, that I shall, in this manner, give in detail the results of two or three experiments of the same nature.

"The air which remained after the calcination of the mercury in this experiment, and which was reduced to $\frac{5}{6}$ of its former bulk, was no longer fit either for respiration or for combustion; animals being introduced into it were suffocated in a few seconds, and when a taper was plunged into it, it was extinguished, as if it had been immersed in water.

"In the next place I took the 45 grains of red matter formed during this experiment, which I put into a small glass retort, having a proper apparatus for receiving such liquid, or gaseous product as might be extracted; having applied a fire to the retort in the furnace, I observed that, in proportion as the red matter became heated, the intensity of its colour augmented. When the retort was almost red-hot, the red matter began gradually to decrease in bulk, and in a few minutes after it disappeared altogether, at the same time $41\frac{1}{2}$ grains of running mercury were collected in the recipient, and 7 or 8 cubical inches of elastic fluid, greatly more capable of supporting both respiration and combustion than atmospherical air, were collected in the bell-glass.

"A part of this air being put into a glass tube of about an inch diameter, showed the following properties: A taper burned in it with dazzling splendour, and charcoal, instead of consuming quietly, as it does in common air, burnt with a flame, attended with a decrepitating noise, like phosphorus, and threw out such brilliant light that the eyes could hardly endure it. This species of air was discovered almost at the same time by Dr Priestley, Mr Scheele and myself. Dr Priestley gave it the name of 'dephlogisticated air'; Mr Scheele called it 'empyreal air'; at first I named it 'highly respirable air,' to which has since been substituted the term of 'vital air.'"

Oxygen is now largely made by liquefying the air and "distilling" the liquid. The nitrogen boils away first, and then the receiver is changed and oxygen is collected. It is stored under pressure in strong steel cylinders, and is used when men are engaged on rescue work in mines or other places where the breathing of foul gases would be dangerous.

Oxygen—Prepare samples of oxygen by heating red calx of mercury in a test-tube, collecting the gas in another test-tube, using the apparatus shown in the diagram. Collect several test-tubes full of the gas and perform the following experiments, in each case making notes of what you observe.

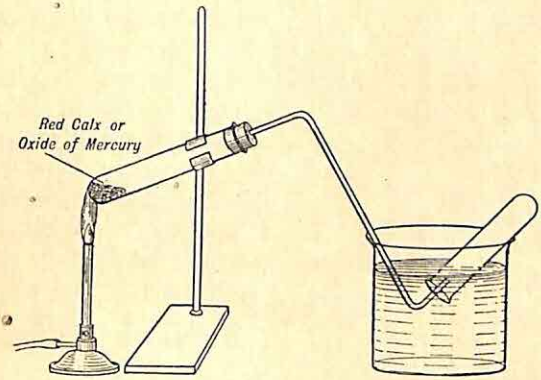


Fig. 143.

Experiment 1

Clamp one tube so that it stands inverted in a beaker of water, and leave for some time with a view to finding out whether or not the gas is very soluble in water. This experiment might be tried with distilled water as well as tap-water. Note the colour of the gas.

Experiment 2

Try effect of the gas on lime-water by pouring a little lime-water into a test-tube full of the gas and shaking.

Experiment 3

Test whether the gas has any effect on the vegetable dye litmus.

Experiment 4

Bring a glowing chip into the mouth of the test-tube full of the gas, and note what happens.

Big-scale Experiments—To show the combustion which takes place in oxygen a little more effectively than can be done in a test-tube, gas-jars full of the gas will be required. The substance to be burned is placed in the cup of a deflagrating spoon (fig. 144); the guard plate must be so adjusted that the cup of the deflagrating spoon reaches about half-way down the gas-jar. If an oxygen cylinder is available, the gas-jars may be filled directly from the oxygen cylinder.

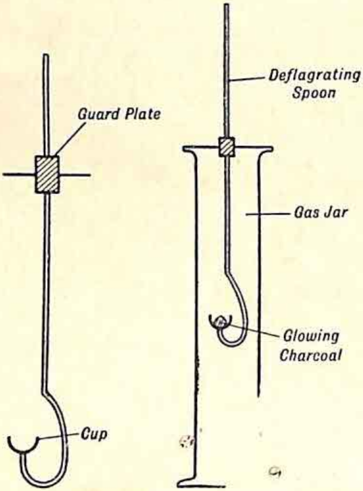


FIG. 144.

Experiment—Place a piece of charcoal in the cup of the deflagrating spoon and bring it to a red glow by heating in the Bunsen flame. *Does the carbon burn easily in air?* Suddenly plunge it into a gas-jar, and note what happens. *Does it burn easily in oxygen?* After allowing it to burn as long as possible, remove the deflagrating spoon from the gas-jar and cover it with a greased glass plate. Add a little lime-water to the gas left in the jar, shake, and describe what happens. Repeat the same experiment, testing the residual gas this time with litmus.

In a similar way note the combustion of (*a*) sulphur, (*b*) iron wire,[1] (*c*) phosphorus, (*d*) magnesium, in air and in oxygen. In the case of iron wire it is wise to tie a piece of match-stalk to the wire to act as tinder (fig. 145). The match-stalk is lighted in the Bunsen flame before plunging into the jar full of oxygen. *It is important that only a very small piece of phosphorus is used in* (c).

---

[1] It is advisable to place a layer of sand at the bottom of the jar in this case.

The gas formed when carbon burns in oxygen is called carbon dioxide, and this gas has the property of forming a white insoluble substance with lime-water. The white substance is called chalk, and the reaction serves as a test for carbon dioxide. The gas carbon dioxide will also turn litmus red. Substances which have this effect on litmus are called **acids.**

It has now been learnt that when substances burn in oxygen they do so more vigorously than in ordinary air. The substances formed are called **oxides.**

Now let us consider what happens when we breathe. Air (one-fifth oxygen, four-fifths nitrogen) is taken into the lungs, and there it meets substances containing carbon carried from various parts of the body in the blood-stream. The oxygen combines with this carbon and forms carbon dioxide. If pure oxygen were breathed this process would take place far too vigorously for normal health, and dangerous results would follow. In cases of pneumonia and other bronchial diseases, pure oxygen is sometimes administered to the patients. This is because it is necessary to bring about a rapid oxidation of the waste products that have accumulated to such an extent as to make breathing difficult.

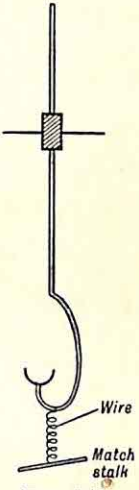


FIG. 145.

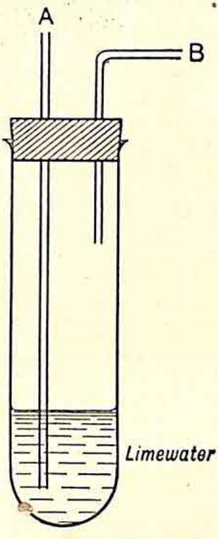


FIG. 146
Breathing through lime-water

The difference between ordinary Air and respired Air—The following experiments will show quite clearly the difference between the air we breathe *into*, and the air we breathe *out of*, our lungs.

Fit up a test-tube as shown in fig. 146. The test-tube contains lime-water. Half of the class should blow down A in one set of test-tubes, the other half drawing air through B in the other set. In the first case it is the air *passing out from* the lungs which enters the lime-water, and in the second case it is the air *entering* the lungs which passes through the lime-water. State clearly the difference you observe. The following experiment may also be used as a demonstration of the process of breathing.

Two bottles containing clear lime-water are connected by glass tubes, as shown in fig. 147. Air is breathed in and out through A. It enters the bottle X *via* the tube B, and the respired air passes into the bottle Y and escapes through the tube C. It is observed that the lime-water in X remains clear, whereas that in Y becomes white, thus indicating that carbon dioxide is passing out from the lungs. In addition to the carbon dioxide, the original nitrogen breathed in is also breathed out, and if breathing through the tube A takes place for some long time, it will be found that the gas in Y above the lime-water no longer supports combustion. Thus we can say that in the process of breathing, oxygen and nitrogen (and of course water vapour) are breathed into the lungs, and carbon dioxide, nitrogen, and water vapour are breathed out. This process of breathing applies to all animals. Only a small proportion of the oxygen passing into the lungs becomes carbon dioxide.

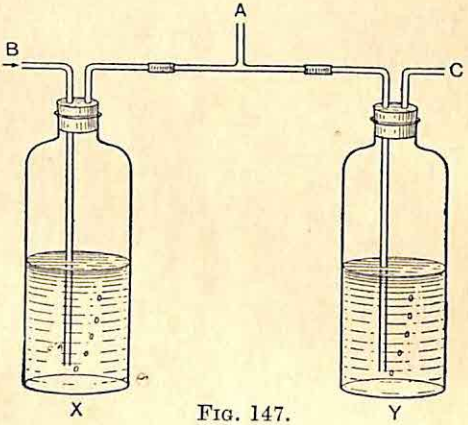


FIG. 147.

QUESTIONS AND EXERCISES

1. Describe experiments to show that the inner cone of the non-luminous flame of the Bunsen burner is (*a*) cold, (*b*) contains unburnt gas.

2. By what experiments would you determine the hottest part of a Bunsen flame ?

3. One commonly says, "Light the gas." Is this strictly correct ? Describe an experiment to support your statement.

4. When a gas fire is turned low it may "light back." How could this be prevented ?

5. What is meant by the term "ignition point" of a gas or vapour ?

6. Describe the principle of the miner's safety lamp.

7. You are provided with a sample of muddy sea-water. How would you obtain from it (*a*) some clean salt, (*b*) some pure water ?

8. Explain why rain-water is sometimes purer than tap-water.

9. When you buy a fresh supply of washing-soda the crystals are quite colourless, but in standing in the open jar in the house they become coated with a white powdery substance. Try to explain this.

10. What is meant by "water of crystallisation" ? How would you find the percentage weight of water of crystallisation in copper sulphate crystals ?

11. A garden roller is 2 ft. in diameter and 30 in. wide. How many square feet of ground will it cover when it revolves 28 times ? ($\pi = \frac{22}{7}$.)

12. Find the cost of the gold leaf necessary to gild a sphere 7 ft. diameter. The leaf costs 1s. a square foot.

13. Calculate the volume of the Great Pyramid of Gizeh in cubic yards. Base 756 ft. square and perpendicular height 480 ft.

14. A sphere 2 ft. diameter is pressed into a cylinder which is also 2 ft. in diameter and 2 ft. high. What is the nearest whole number of gallons of water which can now be poured in? (1 cu. ft. of water weighs 1000 oz.; 1 gallon of water weighs 10 lb.)

15. A relative density bottle weighs 30·00 grm. When full of water it weighs 55·00 grm. When full of turpentine it weighs 51·25 grm. Find the relative density of turpentine.

16. Assuming that 1 c.c. of water weighs 1 grm. and 1 cu. ft. of water weighs 62·5 lb., fill in the blank columns below.

No.	Substance	(*a*) Weight. grm.	(*b*) Volume. c.c.	(*c*) Density. grm./c.c.	(*d*) Density. lb./cu. ft.
i	Aluminium	81·0	30		
ii	Lead .	45·6	4		
iii	Wood .	60·0	80		
iv	Glass .	27·5	11		
v	Tin . .		20	7·3	
vi	Ice . .		10	0·92	
vii	Cork .		50	0·20	
viii	Gold .	38·6			1208
ix	Iron .	77·0			481
x	Petrol .	34·0			53

17. Find the relative density of the following :—

No.	Substance	Weight. grm.	Weight of relative density bottle full of water. grm.	Weight of bottle full of water with substance inside. grm.
i	Iron filings .	1·54	50·0	51·34
ii	Copper turnings	0·89	50·0	50·79
iii	Glass beads .	1·25	50·0	50·75
iv	Lead shot .	2·85	60·0	62·60

18. A piece of ore weighs 200 grm. in air and 150 grm. when totally immersed in water. Calculate (*a*) the volume of the ore; (*b*) its relative density.

19. A piece of metal of relative density 7 weighs 35 grm. in air. What will it weigh in water ?

20. A piece of copper weighs 8·8 grm. in air and 7·8 grm. in water. What will it weigh in methylated spirit of density 0·8 ?

21. Explain why an egg may float in salt water and yet sink in fresh water.

22. A beaker of water stands on the pan of a spring-balance. The spring-balance then reads 170 grm. A stone suspended by a thread is lowered into the water until just immersed but not touching the bottom, and the reading of the balance is then 190 grm. When the stone is allowed to rest on the bottom of the beaker the balance reads 220 grm. Account for the variations in these readings and find the relative density of the stone.

23. Describe an experiment showing the relation between the weight of a floating body and the weight of liquid displaced by it.

A block of wood 100 c.c. in volume and relative density 0·8 floats in water. What volume is immersed ? What weight would be necessary to push it down until just totally immersed ?

24. Describe *three* experiments to show that air exerts a pressure.

25. How would you fit up an apparatus to measure the pressure of the atmosphere ? How does the reading of this instrument vary (*a*) if taken up a mountain, (*b*) if taken down a coal mine ?

26. Describe an aneroid barometer. Why is it sometimes called a weather-glass ?

27. How would you show that approximately one-fifth of the volume of the air is concerned with combustion ?

28. Lavoisier set out to show that when substances burned in air the products were heavier than the original substance by exactly the weight which the air had lost. Describe carefully the experiments he used to show this.

29. Describe a laboratory method for the preparation of oxygen. What are the chief uses to which the gas is put ?

30. Describe four experiments which show that oxygen is a very good supporter of combustion.

31. What differences exist between ordinary air and respired air?

ANSWERS

11. 440 sq. ft. **12.** £7, 14s. **13.** 3,386,880.

14. 13 gallons. **15.** 0·85.

16.

	(*c*)	(*d*)		(*a*)	(*d*)		(*b*)	(*c*)
(i)	2·7	168·5	(v)	146	456	(viii)	2·0	19·3
(ii)	11·4	712·5	(vi)	9·2	57·5	(ix)	10·0	7·7
(iii)	0·75	46·8	(vii)	10	12·5	(x)	40·0	0·85
(iv)	2·5	156·25						

17. (i) 7·7 ; (ii) 8·9 ; (iii) 2·5 ; (iv) 11·4.

18. (*a*) 50 c.c. ; (*b*) 4. **19.** 30 grm. **20.** 8·0 grm. **22.** 2·5.

23. 80 c.c. 20 grm.

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